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The Effect of Simulated Louisiana Summer Conditions on Newborn Dairy Calves. I. Growth, Feed Intake, Digestibility, Plasma Proteins, and Certain Other Blood Constituents.

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THE EFFECT OF SIMULATED LOUISIANA SUMMER CONDITIONS ON NEWBORN DAIRY CALVES. I. GROWTH, FEED INTAKE, DIGESTIBILITY, PLASMA PROTEINS, AND CERTAIN OTHER BLOOD CONSTITUENTS

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ABSTRACT

This investigation was undertaken to augment the limited present knowledge concerning the effects of hot environmental conditions upon new born calves.

Two similar groups of five female and four male Holstein calves were housed in individual stalls either in a psychrometric chamber where air temperature cycled diurnally between 75° and 95°F and with constant vapor pressure at 20 mm. Hg. (experimental group), or in an open-air barn during the winter months (control group). When possible each calf remained on the experiment from 4 to 90 days of age, but the experiment was terminated when the final four calves of each group were between the ages of 60 and 90 days, because the period of availability of the psychrometric chamber for this experiment was limited. The experimental period was analyzed as three separate periods of equal length. During the post-experimental period, which lasted from 91 to 150 days of age, the calves were placed in a common environment and group fed. The calves received whole milk until 3-wk., then skim milk until 8 wk. of age, plus a grain mixture and alfalfa hay ad libitum.

The fact that the experimental-group calves were subjected to thermally stressful conditions was shown by the statistically significant increases in respiration rates and elevations of rectal

temperatures of these calves over the values found in the control-group calves.

The average daily body weight gains of the control-group and experimental-group calves in periods I, II, III, and post-experimental were 0.74 and 0.56, 1.19 and 0.74, 1.50 and 0.56, and 0.94 and 0.64 lb., respectively. The between-group difference was non-significant in period I, but highly significant ($P < 0.01$) in all other periods. The average daily intakes of dry matter from grain and hay of the control-group and experimental-group calves in periods I, II, and III were 0.55 and 0.22, 1.84 and 0.68, and 4.54 and 2.39 lb., respectively. The between-group difference was significant ($P < 0.05$) in period I, and highly significant ($P < 0.01$) in periods II and III. The mean digestibility coefficients determined in seven calves each of the control-group and experimental-group in period III were 69.43 and 66.13 for dry matter, 72.08 and 68.67 for crude protein, 70.43 and 66.60 for total nutrients, and 67.48 and 63.04 for energy, respectively. The between-group differences were statistically nonsignificant.

Blood samples were taken at 5-day intervals during periods I and II and at 10-day intervals during period III. The average hematocrit values found in the control-group and experimental-group calves in periods I, II, and III were 48.4 and 41.8, 40.0 and 33.9, and 37.6 and 31.5%, respectively. The corresponding values for hemoglobin levels were 10.57 and 8.95, 8.75 and 7.08, and 8.56 and

7.05 g. per 100 ml., respectively. These between-group differences were all statistically significant except for hematocrit in period I.

The average plasma carotenoid levels were significantly ($P < 0.05$) higher in the control-group than in the experimental-group calves in periods I and II, but with covariance adjustment for carotenoid intake the between-group differences were nonsignificant. The average plasma vitamin A level of the control-group calves was significantly ($P < 0.01$) higher than that of the experimental-group calves only in period III and most of the variability between groups in period III was due to differences in carotenoid intake.

The average serum total protein levels were significantly higher in the control-group than in the experimental-group calves in all three periods, but with covariance adjustment for protein intake the between group differences were nonsignificant. No significant between-group differences were found for serum albumin level or albumin/globulin ratio, but toward the end of period III the experimental-group calves were showing a decline in those criteria relative to the control-group calves. The average serum alpha-globulin level of the control-group calves was significantly ($P < 0.01$) higher than that of the experimental-group calves in period III (1.18 vs. 1.02 g. per 100 ml.), the between-group difference having grown steadily larger throughout the experimental period. No effect of

treatment on serum beta-globulin level was found. The average serum gamma-globulin level of the experimental-group calves increased from a low initial value throughout the experimental period and exceeded that of the control-group calves, which remained rather constant, toward the end of period III.

INTRODUCTION

The European breeds of dairy cattle are the greatest milk producing breeds in the world. However, these breeds originated under the cool climatic conditions of northern Europe, and attempts to utilize them in regions of hot climatic conditions have not met with equally good success, because of the relatively poor ability of the European breeds to adapt themselves to such environments.

The awakening in recent decades of an appreciation of the importance of climate on the productive performance of dairy cattle has led to a considerable amount of research on climatic physiology. A large amount of data has been collected in connection with the influence of various climatic factors upon several criteria of productivity, including growth, mature body size, milk production, milk composition, feed efficiency, reproductive performance, and longevity. These studies have been conducted in various parts of the world and have involved studies on both temperate and tropical breeds.

The major part of the research on climatic physiology in dairy cattle, which has been done to date, has involved experimentation upon mature animals or upon animals at least one year old. Much less research has been done on younger animals, and there are few published reports of experiments involving newborn calves. Thus, it

was felt that a contribution could be made to existing knowledge in the field of climatic physiology by studying the effect of climatic factors upon newborn calves. The information which such studies could provide might be of practical importance, since the start in life which a young calf secures may exert a decided influence upon its later performance.

The present study was undertaken, therefore, in the hope of adding to the rather limited present store of knowledge on climatic physiology in post-natal calves. Data were secured under controlled conditions of high temperature and high humidity in one group of calves and under cool ambient climatic conditions in a second similar group of calves to enable comparison between heat-stressed and non-stressed calves.

Due to several causes, it was not possible to accumulate a great amount of data in this study. The psychrometric chamber was available for use in this experiment only over a four-month period. The number of calves which could be placed upon the experiment was limited to the number born in the L.S.U. dairy herd during the first two months of this period. Only Holstein calves could be used because inadequate numbers of calves of the other breeds were available. The number of different variables which could be studied in the calves was restricted because of the limited personnel available for conducting the experiment. Nevertheless, it is believed that the present study provides some basic information and may serve as a useful guide to further research in this area.

REVIEW OF LITERATURE

A. General Effects of Heat Stress Upon Young Dairy Calves

1. Growth Rate

The primary objectives in the rearing of dairy calves are to achieve an adequate rate of increase in body size and a normal development of physiological function, which will enable the animals to achieve efficient productive performance in later life. It has been found in many hot climate areas of the world, however, that the growth and development of dairy calves of the European breeds is often far below optimum, or even totally inadequate. Though this observation has been made by numerous breeders, few controlled experiments have been conducted to assess the magnitude of the problem.

Carneiro and Rhoad (28) studied the growth of 103 calves of Holstein, Holstein-Zebu, and Brown Swiss breeding in a tropical region of Brazil. In spite of the fact that these animals received good care and adequate nutrition, the Holstein calves failed to achieve normal growth. The slow rate of growth was first apparent at 4-mo. of age and was quite marked after 6-mo.

Hancock and Payne (46) studied the effect of a warm environment on the growth of European-type cattle, but their animals were

nearly past the calfhood stage when starting on the experiment and the conditions to which they were subjected were not severe. Eight sets of identical-twin heifer calves were divided at about 7.5-mo. of age; one member of each pair was sent to Fiji, while the co-twin remained in New Zealand. The average maximum air temperature at Fiji was 83°F while at New Zealand it was 65°F. Feeding and management practices were kept strictly the same for both groups. Except for an initial setback in the Fiji animals due to transportation and quarantine, there was little difference between the growth rates of the two groups.

Data concerning the effect of artificially-controlled environmental conditions upon the growth of young calves is also limited. Ragsdale et al. (110) maintained three heifer calves each of the Shorthorn, Santa Gertrudis, and Brahman breeds in each of two psychrometric chambers from 1- to 3-mo. of age until about 16-mo. of age. This experiment will henceforth be referred to as the Missouri constant temperature growth study with beef heifers. The atmospheric conditions were maintained constant at 50°F and 62% relative humidity in one chamber and at 80°F and 54% relative humidity in the other chamber. Among the 80°F-reared animals, the Brahmans and Santa Gertrudis grew well, but the Shorthorns grew relatively poorly and at 16-mo. of age averaged about 200 lb. lighter than the heifers of the other two breeds. At 50°F all of the animals made normal growth. The difference in weight gains between the Shorthorns kept at 50°F and 80°F from 4- to 12-mo. was about 147 lb. Predicted mature

weights were 1300 lb. and 1500 lb. for the 80°F Shorthorns and 50°F Shorthorns, respectively. Thus even a mild heat stress was shown to reduce the growth rate of young Shorthorn animals.

Johnson and Ragsdale (57) conducted a study to determine the effect of constant environmental temperatures of 50° and 80°F on the growth of Holstein, Brown Swiss, and Jersey calves from a few weeks to about 1-yr. of age. This experiment will henceforth be referred to as the Missouri constant temperature growth study with dairy heifers. Over the 11.5-mo. test period the average daily gains made by the Holstein, Jersey, and Brown Swiss animals were 2.00, 1.29, and 1.90 lb. respectively, at 50°F and 1.80, 1.25, and 1.89 lb., respectively, at 80°F. Thus the Holsteins and Jerseys made greater gains at 50°F than at 80°F, whereas the Brown Swiss gained equally well at either temperature. After about 8-mo. of age the 80°F animals were gaining weight as rapidly as the 50°F animals, thus it appeared that temperature had influenced the normal age trend in daily gain, or that the 80°F animals had achieved a degree of acclimatization by 8-mo. Nevertheless, it had been demonstrated that mild heat stress stunted the growth of young Jersey and Holstein calves.

Bianca (12) exposed three 4-mo. old Ayrshire bull calves to conditions of 113°F dry-bulb and 81.7°F wet-bulb temperatures for up to 5 hr. each day over a 3-wk. period and found no adverse effects on growth rate. However, the 3-wk. period may have been too short for the heat stress to produce much effect.

Thompson et al. (129) kept ten yearling heifers for 48 days under cool ambient conditions and for 72 days under controlled hot conditions wherein the dry-bulb temperature was cycled between 75°F and 90°F. Mean daily weight gain declined from 1.8 to 1.1 lb. when the animals were moved from cool to hot conditions.

Johnston et al. (62) kept nine yearling heifers,including three Jerseys, three Holsteins, and three Red Sindhi-Holsteins, first under cool conditions of 60° to 70°F dry-bulb temperature for 88 days and then under hot conditions of cycling 75° to 95°F dry-bulb temperature for 40 days. Average daily gain declined during the first 20 days of exposure to hot conditions but recovered during the second 20 days.

It may be concluded that, while young calves of the European breeds are unable to grow normally under heat stress, yearling heifers of the same breeds are less severely affected.

2. Feed Consumption

One of the most obvious explanations for the reduced growth rate of young calves under heat stress is a reduced intake of total nutrients. This supposition is supported by the available data.

Johnson et al. (59) studied the effect of environmental temperature on TDN consumption in the Missouri constant temperature growth study with beef heifers. Consumption of TDN among the 50°F-reared animals was about the same for Shorthorns and Santa Gertrudis and was about 2 lb. per day greater than in the Brahmans. Among the 80°F-reared animals, the TDN consumption of the Shorthorns was less

than that of the other two breeds. Following the growth experiment the same heifers were exposed to various temperatures for short periods to test their heat tolerance. As the environmental temperature was raised from 65° to 90°F the TDN consumption of the Shorthorns declined from 10.4 to 8.7 lb. per day. Raising the environmental temperature from 65° to 105°F depressed the TDN consumption of the Brahmans and Santa Gertrudis only about 1 lb. per day. The TDN consumption of the 50°F-reared heifers was more affected by high temperatures than was that of the 80°F-reared heifers.

Johnson et al. (60) reported that in the Missouri constant temperature growth study with dairy heifers, the Holsteins and Jerseys consumed more TDN at 50° than at 80°F but the Brown Swiss did not. Among the Holsteins the respective TDN consumptions at 50° and 80°F were 2.63 and 2.46 lb. at 1-2 mo. and 4.75 and 3.68 lb. at 2-3 mo. of age. Thus the 50°F-reared Holstein calves consumed more TDN than the 80°F-reared Holstein calves beginning at the youngest ages.

Thompson et al. (129) found that rate of gain and dry matter intake were highly correlated in yearling heifers exposed first to cool ambient conditions and then to hot controlled conditions. Both variables declined under the hot conditions.

Johnston et al. (62) observed in yearling heifers kept under cool conditions for 88 days and then under hot conditions for 40 days that dry matter intake declined during the first 20 days of heat exposure but returned to normal during the second 20 days.

3. Digestibility

In addition to reducing the intake of total nutrients by calves, heat stress might reduce the efficiency of digestion and absorption of the nutrients which are consumed, thereby further decreasing the animal's ability to grow. Very little information is available as to the influence of heat stress on ration digestibility in cattle, and apparently no such data exist in the case of young calves.

Johnston et al. (66) studied 29 lactating Holstein cows over a 4-mo. period during the summer. A group of 9 cows was maintained under air conditioning in a psychrometric chamber. Two other groups of 10 similar cows were either placed in an open shed roofed with galvanized iron or placed on pasture. There was no consistent differences between the chamber group and the shade group in forage dry matter consumption. The mean dry matter digestibility coefficients determined in the chamber group and shade group during four 5-day digestion trials at intervals during the study were 52.5 and 56.2, respectively; the between group difference was statistically significant. The only explanation offered for the increased digestive efficiency of the shade-group was that their higher body temperatures may have stimulated rumen microbiological activity.

Johnston et al. (65), in a subsequent study, found no significant difference in forage digestibility between a group of 10 lactating Holstein cows kept for a 20-day experimental period under air conditioning and a similar group maintained in a shade barn

during hot weather. Forage dry matter consumption was not affected.

Johnston et al. (62) found that apparent dry matter digestibility increased in yearling heifers when exposed to hot conditions. This effect on digestibility may have been an indirect one, however, mediated through decreased dry matter intake, rather than a direct effect of hot conditions on the digestive process.

Davis and Merilan (31) employed a switch-back design with 12 lactating Holstein cows to study the effect of constant air temperatures and relative humidities on feed digestibility. The air temperature and relative humidity conditions of 65°F and 50% were considered as the control. Compared with this, conditions of 80°F and 80% or 90°F and 20% had little effect on dry matter intake or digestibility, but 90°F and 40% produced a decrease of 5.07 lb. in daily dry matter intake and an increase of 4.35% in digestibility, while 90°F and 50% produced a further decrease of 2.37 lb. in daily dry matter intake and a further increase of 1.85% in digestibility.

Graham et al. (42) made digestible energy determinations on two clipped sheep at three feeding levels and at seven environmental temperatures ranging from 8° to 38°C. The amount of energy lost in the feces decreased slightly as environmental temperature increased. The effect was greatest at the highest feeding level where more feces were produced. Using mean regression coefficients for the data points at the medium and high feeding levels, an increase of 10°C in environmental temperature was found to be associated with an increase of 1% in apparent energy digestibility. However, these authors pointed

out that the effect of high environmental temperature in reducing fecal energy loss may have been an artifact caused by continued fermentation of the feces after they were voided. In another study employing three sheep with fleece fed at the medium feeding level, there was a slight nonsignificant decrease in energy loss in feces as the environmental temperature increased in the range 11° to 38°C (17).

Rogersom (15) determined digestible energy in trials with two steers, in which the animals were accustomed to a particular ration for at least 10 days before determinations were made. It was found that the energy loss in feces increased with improving plane of nutrition, but was not significantly affected by environmental temperatures in the range of 20° to 40°C. Blaxter and Wainman (18) found that in two steers maintained at the maintenance level of nutrition there occurred a slight increase in feed digestibility as the environmental temperature increased from 3.8 to 35.1°C.

Johnston et al. (63) found no significant difference in apparent digestibility of dry matter between one group of 10 lactating Holstein cows maintained in an aluminum-roofed open shed during the summer months in Louisiana and another similar group maintained in an air-conditioned barn.

Thus the few data which are available are in agreement in indicating that increasing environmental temperature causes no change or a slight increase in feed digestibility in ruminant animals. However, in most cases the increase in feed digestibility was accompanied

by a decrease in feed consumption, which might of itself increase feed digestibility.

4. Heat Production and Body Temperature

a. Ruminal Heat Production. There appear to be no available data on ruminal temperature or ruminal heat production in young calves. However, as rumen function begins during the early months of life in calves under a normal calf-raising system, ruminal heat production might be an important factor in the over-all heat balance of the calf. The importance of ruminal heat production is indicated from the results of studies on older animals.

Brody et al. (26) measured rectal temperatures and ruminal temperatures at three different depths in the rumina of two dry Jersey cows subjected to four diurnal temperature cycles. The rectal, ruminal, and environmental temperatures tended to vary together in diurnal rhythms. Withholding feed for 24 hr. at environmental temperatures of 62° to 65°F caused a reduction of the ruminal-rectal temperature difference from 4° to 1.5°F. Feeding 4 lb. hay to a fasted cow caused the ruminal temperature to increase 3°F within 25 min., whereas the rectal temperature remained practically constant.

Noffsinger et al. (97) measured rectal and ruminal temperatures in sheep and found ruminal temperature to be generally higher and more variable, except during fasting or immediately after water consumption. These authors concluded that heat produced in the rumen contributes an important part of the total heat load of the animal.

It is probable that the favorable effects on milk production of feeding a low-fiber ration to lactating cows under hot conditions, reported by several workers (24, 92, 104, 118, 120), can be ascribed to less ruminal heat production than occurs when a high-fiber ration is fed.

b. Metabolic Heat Production. When cattle are subjected to sufficiently hot conditions it becomes impossible for them to dissipate enough heat to match their heat gain, thus their body temperature rises. If such conditions persist for an extended period of time, older animals tend to respond by decreasing their metabolic heat production, thus eliminating part of their total heat load (61, 72). In the case of young calves, however, few data are available with regard to the metabolic heat production responses to hot conditions.

Bianca (15) exposed 4-mo. old Ayrshire bull calves to conditions of 40°C dry-bulb and 38°C wet-bulb-temperatures for up to 110 min. each day for 1 to 2 wk. As the animals became better adjusted to the hot conditions, rectal temperature and skin temperature for a given time of exposure progressively declined. In addition, there was a progressive fall in initial rectal temperature, which suggested a decline in resting metabolic rate.

Kibler (68) found in the Missouri constant temperature growth study with beef heifers that at both 50° and 80°F, heat production per unit body weight was highest in the Shorthorns and lowest in the Brahmans, with the Santa Gertrudis being intermediate. Thus, metabolic heat production was inversely related to heat tolerance. The

heat intolerance of the Shorthorns was indicated by the fact that at 80°F the animals of this breed maintained about a 2°F higher rectal temperature than the animals of the other two breeds. From the graphic presentation of the data it appeared that heat production per unit surface area was lower in the 80°F-reared Shorthorns than in the 50°F-reared Shorthorns up to about 10-mo. of age. However, the stunted 80°F-reared Shorthorns showed a higher heat production per unit body weight than the 50°F-reared Shorthorns after about 5-mo. of age.

In the Missouri constant temperature growth study with dairy heifers it was found that the lighter weight 80°F Holstein group had the same energy metabolism as the heavier 50°F Holstein group (69). Kibler suggested that this unexpected result may have been due to an increased energy requirement for greater respiratory activity in the 80°F-reared Holsteins which offset their smaller maintenance energy requirement. The rectal temperatures remained elevated about 1°F in the 80°F Holstein group throughout the growth period. Kibler interpreted the long-continued elevation in rectal temperature as meaning that either the animals were unable to adapt to 80°F or that upward displacement of body temperature constitutes one form of adaptation (70).

In a follow-up experiment involving the same dairy heifers after they had completed one year on the growth experiment, it was observed that gradually increasing the environmental temperature over a 2.5-mo. period caused decreases in energy metabolism in both 50°F-

and 80°F-reared heifers (70). On the other hand, a rapid increase in environmental temperature from 65° to 110°F in 6 hr. increased energy metabolism. Since fasting the animals 41 hr. previously did not depress the rise in energy metabolism accompanying a rapid increase in environmental temperature, it was concluded that the rise was associated primarily with increased respiratory activity and with the van't Hoff effect.

Rogersom (115) also noted in steers that the short-term effect of a high environmental temperature was an increase in metabolic heat production. The magnitude of the response, however, was dependent upon the plane of nutrition which the animals were under. Other workers have also found an effect of plane of nutrition on the severity of reaction of animals to heat stress, i.e., animals on a high plane of nutrition react more severely (4, 114).

In mature cattle, the decrease in metabolic heat production accompanying long continued exposure to hot conditions has been ascribed to decreased thyroid activity (21, 61). From the available data, it appears that the same is true in younger animals.

Blincoe (19) reported that in the Missouri constant temperature growth study with beef heifers, the 80°F-reared Shorthorns showed a 45% lower thyroid secretory activity than the 50°F-reared Shorthorns. The difference in thyroid secretary activity between the two groups of Santa Gertrudis heifers was slight, while among the two groups of Brahman heifers there was no difference.

In the Missouri constant temperature growth study with dairy heifers, Johnson and Ragsdale found significant differences in thyroid secretory activity for breed x temperature interaction, and age (58). Thyroid secretory activity per unit body weight was highest in the Jerseys, intermediate in the Brown Swiss and lowest in the Holsteins, and it was approximately two fold greater in animals 1- to 3-mo. old than in animals 1-yr. old. In contrast to the results obtained with beef heifers, the thyroid secretory activity in dairy heifers was higher at 80° than at 50°F. In the heat tolerance trials following the growth study, there occurred sharp declines in thyroid secretory activity at high environmental temperatures. The decreases in thyroid secretory activity upon raising the environmental temperature from 35° to 90°F was about 75% for the Jerseys and Brown Swiss and 87% for the Holsteins.

Thompson et al. (129) found that thyroid secretory activity was significantly lower in yearling Holstein heifers under controlled hot conditions than under cool ambient conditions.

5. Respiratory Function

a. Respiration Rate. One of the first responses observed in cattle subjected to hot conditions is an increase in respiration rate (64).

Beakley and Findlay (8) exposed 4-mo. old Ayrshire bull calves in 6-hr. periods to air temperatures, ranging from 15 to 40°C with either high or low humidity at the higher temperatures. Respiration ate rose to a maximum value during the second to third hour of

exposure; the magnitude of the maximum value varied linearly with air temperature by 4.9 respirations per minute per °C. The respiration rates observed at 30° and 35°C with high humidity were higher than those observed at the same air temperatures with low humidity. It was estimated that 30° and 35°C air temperatures with high humidity had the same effect on respiration rate as air temperatures of 33° and 46°C, respectively, with low humidity. At 40°C air temperature with high humidity, respiration rate fell precipitously and the amplitude of flank movements increased after about 30-min. of exposure.

Bianca (13) exposed 4-mo. old Ayrshire bull calves to 40°C dry-bulb and 38°C wet-bulb temperatures, then reduced the wet-bulb temperature to 25°C when rectal temperature reached 42°C (after 65 to 110 min.). Upon exposure, the average respiration rate first rose rapidly from 88 to a maximum of 218 and later fell to 167 respirations per minute. At the same time, breathing at first became shallower and then deeper. Bianca designated this phenomenon of decreased breathing rate due to supramaximal stimulation as second-phase breathing. During the latter period the heart rate rose 50 beats per minute for each °C increase in rectal temperature. Second-phase breathing was effective as a cooling mechanism, but it involved strain on the heart and also the risk of respiratory alkalosis. The possibility that intense respiratory activity may produce a condition of alkalosis has been demonstrated in calves by Bianca (11) and in older animals by Dale and Brody (29).

Bianca (14) studied the acclimatization process in 4-mo. old calves exposed to 45°C dry-bulb and 28°C wet-bulb temperatures for 21 successive days for up to 5 hr. each day. As the animals became acclimatized there occurred progressive reductions in rectal temperature, heart rate, respiration rate, and a change from second-phase breathing back to panting in the least heat resistant animals. As soon as the demand for body cooling was reduced due to acclimatization, respiratory rate declined thus it was surmised that a low heat tolerance was associated with high respiration rate and a high heat tolerance was associated with low respiration rate.

Findlay (40) exposed ten 4-mo. old calves for 3-hr. periods to air temperatures of 20°, 30°, and 40°C with either high or low humidity. The three animals which were most heat tolerance, as judged by slowness of rise in rectal temperature, showed large increases in respiratory rate, large decreases in tidal volume and large increases in minute volume. This author concluded that respiration rate alone gives little information about the heat tolerance of calves.

McDowell et al. (90) found that of the several criteria of respiratory activity, respiratory volume was a more sensitive index of heat tolerance than respiratory rate in cows. Furthermore, McDowell (91) found low repeatability coefficients for respiratory rate responses to standard hot conditions.

b. Respiratory Vaporization. Kibler and Yeck (73) reported that in the Missouri constant temperature growth study with beef

heifers, the average percentages of metabolic heat dissipated by respiratory vaporization at the 50° and 80°F environmental temperatures were Brahman 6 and 8, Santa Gertrudis 7 and 11, and Shorthorn 10 and 17, respectively. At these temperatures respiratory vaporization rates were in inverse order to heat tolerance. The high respiratory vaporization and total vaporization rates in the 80°F-reared Shorthorns were associated with high body temperatures and were not evidence of superior vaporization capacity. When the three breeds were equally stressed, as indicated by rectal temperatures, the Brahmans had the highest skin vaporization rates and the lowest respiratory vaporization rates per unit surface area.

Similarly, Taneja (127) found that Zebu x Shorthorn calves 2- to 12-mo. of age had a greater ratio of cutaneous water loss to respiratory water loss than did Shorthorn calves, thus the former animals were relatively less dependent upon respiratory vaporization for cooling.

Kibler et al. (74) reported on the relative importance of respiratory vaporization and skin vaporization observed in the Missouri constant temperature growth study with dairy heifers. Respiratory vaporization accounted for about 8% of the body heat losses at 50°F and for about 12% of the losses at 80°F. Skin vaporization accounted for 15% of the body heat losses at 50°F and for about 41% of the losses at 80°F. Total, respiratory, and skin vaporization rates were all significantly greater at 80°F than at 50°F.

Yeck and Kibler (140) found that Jersey and Holstein cows rapidly adjusted their total vaporization rates to diurnal changes in environmental temperatures. The greater part of the increased total vaporization rate with increasing environmental temperature was due to skin vaporization. Similarly, Knapp and Robinson (78) found that respiratory vaporization accounted for only one-fifth to one-ninth of the total vaporization in a Jersey cow, whereas skin vaporization accounted for a much greater proportion.

Taneja (127) found that rising dry-bulb temperature at constant humidity increased respiratory vaporization, while rising humidity at constant dry-bulb temperature decreased respiratory vaporization in Zebu x Shorthorn and Shorthorn calves. Likewise, Kibler and Brody (71) found that increasing atmospheric humidity at temperatures above 85°F depressed the respiratory vaporization rate in Holstein and Brown Swiss cows. These results are explainable by the fact that with rising humidity the difference in water vapor between exhaled and inhaled air becomes less, thus, unless there is a compensating increase in the volume of respired air, respiratory vaporization decreases. In the studies reported the animals apparently did not increase their respiratory volumes sufficiently at temperatures above 85°F to compensate for increasing humidity.

It can be concluded that the increased respiratory activity in cattle, including calves, under hot conditions is effective in increasing heat dissipation by evaporative cooling, unless the humidity is also very high. Evaporative cooling from the skin surface

is more important, however, especially when the heat stress is severe.

6. Coat Characteristics

According to the results of Turner and Schleger (130), sleek coat is an important factor in favoring heat dissipation by cattle. These authors scored the coats of 1600 animals of various breeds by means of a subjective system and found that the scores were well correlated with body temperatures and respiration rates. However, the plane of nutrition was a confounding factor, as it also had a marked influence on sleekness of coat.

Yeates (139) compared seasonal changes in coat characteristics of a control group of four young Poll Shorthorn cattle with those of a similar group in which the daily photo-period was artificially altered to simulate that of the opposite hemisphere. Heat tolerance tests were conducted at intervals thrice before and once after the coat was clipped. Each group completed a full cycle of coat change within one year, though the summer and winter coats were present during opposite seasons in the two groups. The long, wooly winter coats were associated with poor heat tolerance, while the short, glossy summer coats were associated with better heat tolerance. All of the animals showed relatively good heat tolerance after being clipped.

Bianca (16) also found that 5- to 7-mo. old Ayrshire calves tolerated short term exposure to hot conditions better after clipping than before clipping, as evidenced by significant reductions in skin and rectal temperatures and respiration rate. After clipping

the calves also showed fewer outward signs of heat distress such as protrusion of the tongue, excess salivation, and cessation of rumination than they did before clipping.

Berman and Kibler (9) studied the effect of clipping on 20-mo. old heifers under conditions of 89°F dry-bulb temperature and 69% relative humidity. The rectal temperatures remained practically constant after clipping in spite of drops in respiratory activity and total moisture vaporization. It appeared that these animals reacted to the increase in heat dissipation due to clipping by increasing their feed consumption and heat production.

Yeates (139) concluded that the normal coat changes in cattle are due mainly to seasonal variability in the duration of daylight; coat changes were unrelated to seasonal temperature differences under the conditions of his study. However, Berman and Volcani (10) concluded from a study of Holstein and Syrian x Holstein cattle in Israel that environmental temperature is also an important factor influencing the annual cycle of coat characteristics.

B. Effects of Heat Stress Upon Blood Composition of Young Calves

1. Blood Volume

a. Influence on Apparent Blood Composition. In any investigation of the factors affecting the levels of various blood components it is important to consider concurrent changes in blood volume, in order that the mere effects of hemodilution or hemoconcentration are not interpreted as real changes in the levels of the blood components being studied.

Wehmeyer (133) studied changes in blood composition in Red Dane cattle of various ages and concluded that the changes which occurred during one day or one month could not be related to the state of hydration of the body.

b. Normal Changes with Age. Before an assessment can be made of the effect of heat stress on blood volume in young calves, it is necessary to consider the age trends which normally take place even in unstressed animals. Hansard et al. (47) showed that blood volume is quite high in the newborn calf and decreases rapidly during early life. The blood volume figures found in Hereford cattle at the ages of 2- to 6-days, 3-wk., 6- to 8-mo., and 3-yrs. were 12.0, 8.5, 5.8, and 3.5 ml. per 100 g. body weight, respectively.

c. Changes Due to Hot Environment. In the case of the human it is well established that one of the earliest responses of the body fluids to heat stress is an increased blood volume and hemodilution (7). However, when heat exposure is prolonged more than one week in this species, blood volume decreases toward control values.

Johnston et al. (62) found no consistent effect of controlled climatic conditions on plasma volume in nine heifers of three breeds viz., Jersey, Holstein, and Red Sindhi x Holstein, subjected to both cool and hot conditions.

Dale et al. (30) pointed out that the water balance in slightly-sweating cattle may differ from that in profusely-sweating man at high temperatures. However, their data on Holstein and Jersey cows maintained under four diurnal temperature rhythms indicate

that an increase in blood volume also occurs in cattle upon exposure to hot conditions. In their Holstein cows blood volume increased from 75.7 to 91.6 cc. per kilogram body weight and serum volume increased from 49.2 to 58.4 cc. per kilogram body weight as the temperature rhythm was shifted from the coldest (10° to 40°F) to the hottest (70° to 100°F).

Blincoe and Brody (20) observed no apparent changes in blood water or electrolyte concentration in Jersey, Holstein, Brown Swiss, and Brahman cows nor in Brown Swiss and Brahman heifers upon increasing environmental temperature from 65° to 100°F.

Bianca (12) observed no significant changes from normal in blood volume or plasma volume in 4-mo. old calves exposed to extreme heat for several hours a day over a 3-wk. period. There was a tendency for hemoconcentration to occur on the first day of exposure, however, injection of an adrenaline-like substance caused the same effect, thus the initial transitory hemoconcentration appeared to be a response to stress in general rather than to heat specifically.

Though the available data are not conclusive on this point, the possibility that an increase in blood volume and hemodilution may be at least a temporary response of cattle to hot conditions should be considered in any study of the effects of heat stress on blood composition.

2. Red Blood Cells and Hemoglobin

a. Importance in the Young Calf. Before investigating the effect of heat stress on the red blood cell and hemoglobin picture in calves, it would be well to consider the importance of these blood oxygen-carrying-capacity criteria to the growth and health of calves in general.

Positive correlation between hemoglobin concentration and/or hemotocrit values and growth rate in young calves have been reported in some cases (126, 128). Other reports indicate that no such correlation exists, even in calves which are relatively anemic (52, 87, 111). However, in one case the calves with low hemoglobin levels were easily tired and became dyspneic upon physical exertion, even though their growth rates were not affected (87). In another report blood hemoglobin level was not found to influence basal metabolic rate in milk-fed calves (121).

Further information is needed before it can be concluded whether a high oxygen-carrying capacity of the blood gives the young calf an advantage in growth potential, though it does seem to be favorable for the general health of the animal.

b. Normal Changes with Age. All reports appear to agree that hemoglobin levels are quite high in the calf at birth and decline during the early weeks of life (36, 43, 54, 128, 132, 137). Hematocrit values appear to follow a similar trend (36, 43, 54, 133, 137). The age at which the initial declines in hemoglobin and hematocrit reach a minimum level has been reported as from 3-wk.

(137) to 6- to 9-wk. (128). A decrease in red blood cell counts does not seem to occur in conjunction with the initial decrease in hematocrit values (43, 54). This has been ascribed to a decrease in the average size of the erythrocytes during the early weeks of life (54).

c. Changes Due to Nutritional Status. Greig and Boyne (44) demonstrated that nutritional status affects the hematology of calves. In a study with eight pairs of monozygous twin calves 7- to 9-mo. old, these authors found that animals raised on a high plane of nutrition (110% of the Ragsdale standard) had higher hemoglobin concentrations, hematocrit values, and red blood cell counts than animals raised on a low plane of nutrition (70% of the Ragsdale standard).

McCay (89) found no influence of level of protein feeding over an 18-mo. period on blood hemoglobin concentration in Holstein cows. However, all of the animals on the experiment were probably consuming rations adequate in protein. Protein depletion might well affect the hemoglobin levels in the blood of either old or young cattle.

d. Changes Due to Hot Environment. There do not appear to be any data dealing with the effect of controlled heat stress on red blood cells and hemoglobin changes in young calves. The only available data involve studies on older animals.

Johnston et al. (62) found decreases in erythrocyte volumes in three heifers each of Jersey, Holstein, and Red Sindhi x Holstein

breeding from 1.19 to 0.89, 1.34 to 1.00, and 1.36 to 1.06 liters per 100 kg. body weight, respectively, when the controlled climatic conditions were switched from cool (air temperature cycling from 55° to 70°F) to hot (air temperature cycling from 75° to 95°F and humidity maintained at a dew point of 72°F).

Brody (25) studied two matched groups of Holstein and Jersey cows, one group maintained at air temperatures of 50° to 60°F and the other group subjected to systematically increasing air temperatures from 50° to 100°F. There were no significant differences between the two groups in hemoglobin levels, hematocrit values, or red blood cell counts. From a report on subsequent experiments of similar design, it appeared from graphic presentation of the data that hematocrit values declined slightly in Brahman but not in Jersey or Holstein cows at air temperatures of 90°F and above and that hemoglobin levels declined slightly in Brahman but not in Jersey or Holstein cows at air temperatures of 85°F and above (20).

Dale et al. (30) exposed mature cows to four diurnal temperature rhythms, viz., 10°-40°, 40°-70°, 60°-110°, and 70°-100°F. The hematocrit values in lactating Holsteins and lactating Jerseys remained relatively constant, but in dry Jerseys there was a decline in average hematocrit value from 45.9 to 36.2% upon shifting from the coolest to the hottest conditions.

Melchior and Bateman (92) found correlations between hematocrit and respiration rate and between hematocrit and rectal temperature of $r = -0.51$ and $r = -0.74$, respectively, in cows subjected to 35°C

dry-bulb temperature and 25 mm. Hg vapor pressure.

Several studies have been made of the effect of ambient climatic conditions on red blood cell and hemoglobin changes. Manresa et al. (84) found a correlation between hemoglobin level and atmospheric temperature of $r = -0.23$ in Indian Nellore cattle. In a later study on the same breed a correlation between hemoglobin level and body temperature of $r = -0.18$ was found (83). A study on Philippine native cattle yielded no correlation between hemoglobin level and body temperature, but a negative correlation between hemoglobin level and atmospheric temperature (85).

Garner and Unsworth (41) found a drop in hemoglobin level and red blood cell counts during the summer months in Nigerian cattle. Mullick (96) observed lower hemoglobin levels in the blood of both cattle and buffaloes in India during the rainy season than during the dry season. Patterson et al. (101) found a slight decrease in hemoglobin levels in Jersey and Holstein cows during the summer. However, Rusoff (119) studied 16 purebred Jersey cows and their 16 Red Sindhi x Jersey female progeny over a 2-yr. period and found no evidence of a seasonal trend in hematocrit or hemoglobin values in either group.

It has been suggested that among-breed differences in hemoglobin levels of animals under common environmental conditions give some indication of the relative heat tolerance of the different breeds. Rusoff (119) found that Jersey x Sindhi daughters had significantly higher hematocrit and hemoglobin values than their Jersey dams.

Walker (132) found significantly higher hemoglobin levels in four mature tropical breeds in Northern Rhodesia than in two imported temperate breeds. A correlation of r = 0.26 between hemoglobin level and heat tolerance coefficient of Rhoad was also reported. Manresa and Reyes (86) reported higher hemoglobin levels in two native Philippine breeds than in two imported temperate breeds, and lower values for the latter breeds than are usually found in these same breeds in cooler climates.

In summary, though the data are not consistent, there is some indication that exposure to hot conditions causes decreases in hematocrit values and hemoglobin levels in the blood of cattle, especially in cattle of non-tropical breeds.

3. Carotenoids and Vitamin A

a. Significance in the Young Calf. The significance of blood plasma levels of vitamin A and its precursors depends upon the extent to which these levels reflect the status of vitamin A nutriture in the animal. Since both carotenoids and vitamin A are stored in the liver and other organs besides in the blood, blood plasma levels of these substances may or may not be indicative of the over-all stores which the animal possesses.

Hibbs and Krauss (53) found that plasma vitamin A level and liver stores of the vitamin were not closely correlated in Holstein and Jersey calves except at low levels of liver storage. Braum (23) found that a direct relationship between blood vitamin A and liver vitamin A stores existed in cows only when the latter fell below normal levels. These results may be explained by the hypothesis of

Almquist (1, 2), confirmed by Eaton et al. (38), that plasma vitamin A concentration is linearly related to the logarithm of liver vitamin A concentration. In the case of carotenoids, Bullis (27) found a correlation between blood plasma concentration and liver concentration of $r = 0.84$. Thus blood levels of vitamin A and its precursors do appear to be dependent upon the over-all vitamin A status of the calf, though care must be exercised in interpreting results based on blood studies alone.

The maintenance of adequate blood levels of vitamin A and carotenoids may be important to the long-term well being of the animal, yet there is considerable evidence that these levels have little effect upon the growth rate of young calves. In numerous experiments it has been found that a vitamin A depletion condition severe enough to cause an elevation of the cerebrospinal fluid pressure did not exert any adverse effects upon feed consumption, rate of gain in body weight or other measures of body size, or even upon the incidence and severity of scours (32, 35, 37, 51, 116, 117). In view of these findings, it is doubtful that any moderate depression of the blood levels of carotenoids and vitamin A below the levels considered adequate in young calves can produce any economically significant consequences. Whether or not any physiologically significant consequences can be produced under such conditions is not clear.

b. Normal Changes with Age. There are numerous reports in the literature which indicate that the calf is born with low blood levels of carotenoids and vitamin A (49, 50, 82, 93, 105, 125, 136). An

abrupt increase in the blood levels of these substances occurs upon the consumption of colustrum (93, 105, 125, 136). When colostrum is not fed the usual rise in the blood levels shortly after birth does not occur (125). Two or three days after birth the calf is usually switched from colostrum to whole milk which contains much less carotenoids and vitamin A. Under such circumstances it was found that the blood levels of carotenoids and vitamin A attained a maximum value at about 3-days of age and then began to decline gradually (98, 136). This gradual decline continued until 5- to 6-wk. of age when the calves began to consume sufficient carotenoids from hay to reverse the trend. Blood vitamin A was then found to plateau at a level of 14 to 15 mcg. per 100 ml., whereas blood carotenoids continued to increase, reaching a level of 48 mcg. per 100 ml. at 10-wk. of age (136).

c. Changes Due to Hot Environment. There are several lines of evidence which indicate an involvement of carotenoid and vitamin A metabolism in heat stress in species other than the bovine. In the human it has been found that a febril condition results in a decline in blood levels of these substances (3, 88, 95). Heat stress has been found to decrease blood vitamin A but not blood carotenoid level in the rat (123). Also it has been found easier to produce avitaminosis A in heat-stressed than in non-stressed rats (79). Finally, large doses of vitamin A have been found to increase survival time in rabbits subjected to lethal heat stress (80).

The available data dealing with the effect of hot conditions upon the blood levels of carotenoids and vitamin A in cattle are not extensive and they appear to be limited to studies involving animals at least one year old.

Perry et al. (103) divided 72 yearling Hereford steers in six lots of 12 each. The animals were fed for 6 mo. a basal ration of concentrates, which was adequate in carotenoids according to the National Research Council recommendation, along with supplemental vitamin A at either 0, 2,000, 4,000, 8,000, 16,000, or 32,000 I.U. daily. The unsupplemented steers consumed less feed and grew more slowly than the supplemented steers. The vitamin A deficiency symptoms shown by the unsupplemented steers were more severe during the hot summer months. There was a correlation between the seasonal increase in temperature and the lowering of plasma vitamin A levels in the unsupplemented steers. During the hottest month the unsupplemented steers showed a 50% decrease in plasma vitamin A level, while the group supplemented with 32,000 I.U. of vitamin A showed a decrease of only 15% in plasma vitamin A level.

Stallcup and Herman (124) studied two groups of lactating cows, each consisting of two Jerseys, two Brahmans, and two Holsteins. One group was subjected to air temperatures of 50° to 60°F, while the other group was subjected to air temperatures which were increased from 50° to 105°F by 5° or 10°F intervals. Prior to the start of the experiment the animals of both groups had been on pasture and therefore had high blood plasma carotenoid concentrations. After the start of the experiment the plasma carotenoid levels decreased in

both groups, with no significant differences being observed between groups. The plasma vitamin A levels were variable in both groups and showed no significant effect of treatment. These authors concluded that blood plasma levels of carotenoids and vitamin A are not significantly influenced by high environmental temperature.

Page et al. (98) reported the results from two Arizona experiments. The first experiment was of 18-days duration and employed three sets of twin Holstein yearling steers. One member of each twin set was maintained under controlled conditions of 75° to 89°F air temperature, while the co-twin was penned under shade outdoors where the average ambient temperature range was 72° to 101°F. All the animals were fed 6 mg. carotenoid per 100 lb. body weight daily. From biopsies performed at the beginning and at the end of the experimental period, it was found that the animals maintained at the higher ambient temperatures lost three times more vitamin A than the animals in the cooler environment.

In the second Arizona experiment, four sets of identical-twin yearling cattle including Holstein, Santa Gertrudis, and cross-bred animals were pre-treated with a carotenoid-free ration for 105 days. During the first treatment phase, one member of each twin set was exposed to solar radiation, while the co-twin remained in the shade. During the second treatment phase, a fish oil supplement was injected intraruminally at one of two levels to both members of each set. The animals exposed to solar radiation showed a 33.3% loss of liver vitamin A during the experimental period, while the

animals kept under shade showed only a 13.2% loss. Following vitamin A administration, the amount of vitamin A present in the blood was greater in the animals previously exposed to sunlight than in those previously kept under shade.

Page et al. (99), in a later experiment, fed four sets of identical-twin yearling cattle a carotenoid-free ration for 6 mo. prior to and during the experimental period. One member of each twin set was subjected to solar radiation, whereas the co-twin was penned under shade during periods of high air temperature. No significant effect of treatment on blood vitamin A level was found.

Erwin (39) found significantly higher blood serum concentrations of carotenoids and vitamin A in 12 Brahman cows than in 10 Angus cows with 10 Angus x Brahman cows showing intermediate values. The animals were all 2- to 6-yr. old, were all reared in the same environment, and all grazed the same alfalfa pasture. If these breed differences are real, they might have some bearing on the greater heat tolerance of Brahman and of Brahman crossbred cows than of Angus cows.

In summary, the available data are not derived from very well planned experiments and they are inadequate to allow a definite assessment of the effect of heat stress upon blood levels of carotenoids and vitamin A in cattle. There is, however, some indication that vitamin A metabolism in cattle is affected by heat stress.

4. Serum Protein

a. Normal Changes with Age. Larson and Touchberry (81) studies blood samples taken from 300 cattle of several dairy breeds

and found that the serum total protein concentrations were lower in young animals than in mature animals. The average serum total protein concentration increased from about 5.8 g. per 100 ml. during the first months of life to 7.4 g. per 100 ml. at 4-yr. of age. Wehmeyer (133) found that the serum total protein concentration in Red Dane cattle rose from 4.86 g. per 100 ml. at 5-days of age to 7.41 g. per 100 ml. at 19-mo. of age.

Several workers have reported that there are abrupt changes in the various serum protein fractions of the newborn calf after the consumption of colostrum (48, 55, 56, 81, 122). These changes are attributable to the fact that the gut wall of the newborn calf is permeable to whole proteins (6, 34). The changes produced by the ingestion of colostrum are an increase in the gamma-globulin and slower-migrating beta-globulin fractions and a decrease in the albumin, alpha-globulin, and faster-migrating beta-globulin fractions. All of the proteins of colostrum are absorbed with equal efficiency by the newborn calf, but the proteins of smaller molecular size leave the circulation at a greater rate than the proteins of larger molecular size because of the proteinuria which occurs in the newborn calf (6, 34, 107, 108, 109).

The sharp drop in the alpha-globulin fraction of the serum proteins which occurs in the calf during early life (48, 56, 81, 107, 122, 131), is believed to be due to a loss of the alpha-globulins associated with the protein called fetuin (33, 81, 102, 107).

Following the initial rapid changes in serum protein fractions shortly after birth, these fractions tend to gradually approach levels found in the adult animal. In several studies the albumin fraction increased during the first few weeks or months of life (48, 81, 131, 133). After the initial decline for the first month or two, the alpha-globulin fraction remained fairly constant or increased slightly (81, 131). The beta-globulin fraction increased slowly (131), or showed an irregular decrease (107). The gamma-globulin fraction decreased in a linear fashion for the first two months (107, 131), then showed a slight increase during the third month (107). The most important long-term trend with age was found to be an increase in the beta- and gamma-globulins associated with immunity (81).

b. Changes Due to Hot Environment. There is not a great amount of data dealing with the effect of hot conditions on serum proteins in cattle. The data which are available were obtained from studies on animals at least one year old and they are concerned with the effect of hot conditions on serum total protein rather than on individual serum protein fractions.

Kamal et al. (67) studied plasma protein changes in the animals which had been used in the Missouri constant temperature growth study with dairy heifers during a subsequent study in which the animals were exposed to various environmental temperatures. Raising the environmental temperatures from 50° to 95°F caused a progressive decline in plasma protein concentration in both 50°F- and

80°F-reared heifers. These authors attributed the decline in plasma protein concentration to a probable increase in plasma volume and to a marked decrease in nitrogen intake. The 80°F-reared heifers showed a significantly slower decline in plasma protein concentration than did the 50°F-reared heifers with rising environmental temperature. Since the difference between the two groups in average nitrogen consumption was not significant, the slower decline in the 80°F-reared heifers was attributed to a slower increase in plasma volume.

Earlier reports from the Missouri Station indicated that hot conditions did not affect serum total protein concentration. Brody (25) found that increasing environmental temperature from 50° to 100°F at intervals did not alter the plasma protein concentrations in a group of cows consisting of three lactating Jerseys, two lactating Holstein, and one non-lactating Holstein. Blincoe and Brody (20) reported no apparent change in blood colloid concentration upon increasing the environmental temperature from 65° to 100°F in studies with cows and heifers of several breeds. Dale et al. (30) found no consistent changes in serum water percentage in nine European-breed cows subjected to four diurnal temperature rhythms ranging from cold to hot, and thus concluded that serum protein osmotic pressure must have remained relatively constant.

More information is needed before the influence of heat stress on the serum proteins of cattle can be established.

C. Relative Heat Tolerance of Young Calves and Older Cattle

All available reports seem to agree that young calves are more severely affected by exposure to hot conditions than are older animals, and this concept appears to be universally accepted. It would appear, however, that the acceptance of this concept is not based upon the results of any great amount of careful research under controlled conditions.

According to Bonsma (22), work done in South Africa indicates that an animal's heat tolerance coefficient increases with age. This author contends that if a calf can tolerate atmospheric temperatures above 85°F during its first year, then it will possess a high degree of resistance to subtropical conditions as a mature animal.

Asker et al. (4) determined heat tolerance coefficients in Egyptian cattle, buffaloes and high-grade Shorthorns under ambient conditions. Calves 1-yr. old were found to have lower heat tolerance coefficients than either 2-year. old or mature animals.

Riek and Lee (113) compared the reactions of four 8-wk. old Jersey calves, subjected to controlled conditions of 85° to 110° dry-bulb temperatures with varying humidities for 7 hr. twice a week for 9 wk., with the reactions of four Jersey cows, subjected to similar conditions in a previous experiment (112). The rectal temperature and respiration rate responses of the calves to hot conditions were more marked than those of the cows in that they showed a more rapid initial rise and reached higher equilibrium values. There

were no marked differences between calves and cows in evaporative weight loss per unit body weight, but per unit body surface area the evaporative loss was less for calves than for cows, which suggested a lower efficiency of sweating in the calves. These authors concluded that calves suffer a greater strain than cows under a given heat stress.

Klemm and Robinson (77) performed three series of heat stress tirals on two Australian Illawara Shorthorn (A.I.S.) bull calves and two Zebu x Hereford bull calves. The ages of the animals at the beginning of the first, second, and third series were 1-mo., 6-mo., and 11.5-mo., respectively. In each series the animals were subjected to 7-hr. exposures twice a week for 6 wk. to dry-bulb temperatures of 86° to 108.5°F with varying humidities. As the calves became older their panting rate under a given hot environment decreased. The Zebu x Hereford calves showed a high skin vaporization rate soon after birth and a continued increase up to 12-mo. of age. Skin vaporization rate was low in the A.I.S. calves at 1- to 3-mo., but it increased somewhat with age, though it never equalled the high rate of the Zebu x Herefords. These authors concluded that heat tolerance improves rapidly in growing calves of all breeds.

Taneja (127) exposed three calves, one A.I.S., one Shorthorn, and one Zebu x A.I.S., to standard hot conditions at the three ages 4-, 8-, and 12-mo. With advancing age, the skin vaporization rates of all the calves increased, but the respiratory vaporization rates remained nearly constant. Thus the increase in heat tolerance which

occurred as the animals became older appeared to be due to more efficient sweating.

Kibler (68) noted that heat production per unit surface area rose to a maximum at 6-mo. of age and subsequently declined in the animals on the Missouri constant temperature growth study with beef heifers. This author speculated that the decrease in heat production per unit surface area after 6-mo. of age may explain why cows are more heat tolerant than calves.

It has also been suggested that coat characteristics may be a factor in the inferior heat tolerance of calves relative to that of older animals. Hafez (45) reported that Egyptian buffalo calves at birth possessed a hair coat three times as dense as that of adult animals of the same breed. Turner and Schleger (130), in applying their subjective coat scoring system to cattle of various breeds, found a steady decline in mean cost score year by year from calves to 3-yr. olds.

Walker (132) suggested that the changes in blood hemoglobin level which take place as the calf grows older tend to enhance heat tolerance. In comparing tropical and temperate breeds, he found that the tropical breeds reached a stable hemoglobin level more rapidly. Changes in hemoglobin level with age were associated with similar inverse changes in heat tolerance, and the rapidity of change of one was closely correlated with the development of the other.

It appears that several physiological mechanisms may be involved in the increase in heat tolerance which takes place in the

calf as it becomes older. More research will be needed before these mechanisms are well understood.

In view of the greater sensitivity of calves than of older cattle to heat stress, it would seem that the sparse knowledge presently available about the physiological responses of calves to hot conditions is a detriment to progress in adapting highly productive breeds of dairy cattle to tropical and subtropical areas of the world.

EXPERIMENTAL METHODS

A. Statement of the Problem

The effect of high environmental temperature and the additional effect of high humidity on dairy cattle of both temperate and tropical breeds has been the subject of a large amount of research. The vast majority of the experimental results, both from studies involving animals kept under climatic control chamber conditions and under natural climatic conditions, have shown that animals under heat stress are at a disadvantage in productive capacity relative to animals not under stress. Few experiments have been conducted, however, to determine the magnitude of the adverse effect of heat stress on the productive performance of young calves. One of the primary objectives of the present study, therefore, was to provide additional information in this regard.

Although the fact that heat stress decreases the productivity of dairy cattle is now fully appreciated, much remains to be learned about the physiological adjustments which are responsible for this loss of productive function. It is known that the centers for heat conservation and heat loss are located in the hypothalamus and that these centers emit nervous impulses which stimulate or depress the functional activity of other organs. For example, in the heat-stressed animal, the mechanism which regulates secretion of the

thyroid hormone responds to stimuli from the hypothalamic heat regulatory centers to produce a diminution of this function. Numerous other organs, both endocrine and non-endocrine, may also respond in ways which are presently unknown to stimuli from the hypothalamic heat regulatory centers, as well as to local stimuli produced by heat exposure. A second objective of the present study was to investigate possible effects of heat exposure on certain organs and systems of the young calf's body, notably the blood and digestive system.

B. Experimental Design

All Holstein calves dropped in the Louisiana State University herd between November 27, 1961 and January 31, 1962, which survived the first three days of life, were included in this experiment. As the calves were born, they were allotted randomly within sex either to the experimental group or to the control group. Thus the design of the experiment was completely randomized with the limitation of equalization of sexes. The total number of animals which were placed on the experiment was 20. Two of the calves, both bull calves in the experimental group, died during the experiment and all of the data from these animals were omitted from the results. Each group finally consisted of nine calves, including five heifer calves and four bull calves. The identification number, sex, date of birth, and weight at birth of each animal used in the experiment are given in Table 1.

TABLE 1

Calves employed in the experiment

Control Group				Experimental Group			
Identification number	Sex	Date of birth	Weight at birth (lb.)	Identification number	Sex	Date of birth	Weight at birth (lb.)
631	F	11-27-61	69	632	F	11-28-61	97
633	F	12-1-61	72	438-1	M	12-1-61	72
531-1	M	12-8-61	83	634	F	12-7-61	72
636	F	12-21-61	92	635	F	12-19-61	83
510-1	M	1-2-62	86	637	F	12-23-61	70
296-4	M	1-7-62	100	446-1	M	1-3-62	64
638	F	1-16-62	72	75-3	M	1-15-62	60
478-1	M	1-20-62	121	639	F	1-26-62	100
640	F	1-31-62	60	602-1	M	1-27-62	100
Mean			83.9				79.8

C. Feeding and Management

All the calves were treated the same during the first 3 days of life. They remained with their dams the first day; during the second and third day they were kept in elevated stalls at the university calf barn and were fed colostrum from a nipple pail at the rate of 3 to 4 lb. per day. At the start of the fourth day of life the animals were placed upon the experiment. The animals in the experimental group were moved to the climatic control chamber during the evening of their third day of life, since this was the time of day at which the temperature in the chamber was lowest, and this procedure gave the animals a chance to adjust to their new surroundings before the heat was turned up again the next morning. The animals in the control group remained in the elevated stalls at the university calf barn for the duration of the experiment. A sufficient number of the elevated stalls were moved to the climatic control chamber to accommodate the experimental group calves. Bagasse bedding was used with both groups. Manure and wet bedding were removed from each stall daily.

The same feeding practices were employed with both groups. The calves received whole milk from the 4th day of life until 3-wk. of age. Whole milk feeding was gradually increased from 4 lb. per day on the 4th day to 7 lb. per day, at which level it was maintained until the animals were switched to reconstituted skim milk at 3-wk. of age. Skim milk was gradually substituted for whole milk over a 4-day period. Full skim milk feeding began at the level of

8 lb. per day and was raised by 1 lb. increments at approximately weekly intervals to 12 lb. per day at 8-wk. of age. At this stage the calves were gradually switched to water over a 4-day period. The daily water allowance was maintained at 14 or 16 lb., depending upon feed consumption, until the completion of the experiment at 90 days of age. No cases were encountered in which the calves would not drink all of their whole milk or skim milk allowances. Water refusals were also very infrequent. Milk or water allowances were reduced in cases of scours. Scouring animals were also treated with antibiotic-containing scours pills. However, the incidence of scours was not great.

A calf grain mixture was placed in front of the animals as soon as they started on the experiment. Excellent quality alfalfa hay was also fed beginning at about 1-wk. of age. Hay was fed ad libitum and grain was fed ad libitum up to a limit of 6 lb. per calf daily. Grain and hay were fed once a day and refused grain and hay from the previous day were weighed back at that time. All grain and hay consumption data were recorded to the nearest one-tenth pound. A clean grain bucket was used each day. Block salt was also kept in front of each calf. The daily feeding routine is summarized in Table 2.

Feed samples were collected at intervals during the experiment and composited for chemical analysis. A composite grain sample was kept under refrigeration and a composite hay sample was frozen for subsequent determinations of carotenoid content. When ready for

TABLE 2

Daily feeding routine employed in the experiment

Feeding	Time	
	Experimental Group	Control Group
Morning milk or water	6:00 a.m.	6:30 a.m.
Grain and hay	4:00 p.m.	3:00 p.m.
Afternoon milk or water	5:00 p.m.	5:30 p.m.

analysis, the feed samples were thoroughly mixed and coarsely ground. The samples for carotenoid analysis were subjected to an additional fine grinding to pass a 60-mesh screen. All chemical analyses were made according to standard A.O.A.C. procedure (5). The chemical composition of all feeds fed during the experimental and post-experimental periods are given in Table 3.

D. Length of Experiment and Post-experimental Period.

The experiment was initiated on December 1, 1961 and continued until March 29, 1962, when it had to be terminated because the psychrometric chamber no longer was available for use in this experiment. This situation was unfortunate, but it was unavoidable because the chamber had been previously committed to another experiment, the start of which could not be postponed any longer. At the time the experiment ended five of the animals in each group had completed the 90-day experimental period and had been moved to the outside pens at the university calf barn. The four remaining animals

TABLE 3

Chemical analyses of composite hay and grain sample
(dry weight basis)

Sample	Dry matter	Crude protein	Ether extract	Crude fiber	Nitrogen-free extract	Ash	Caro-tenoids	Gross energy
	(%)						mg./lb.	cal./g.
Experimental period								
Alfalfa hay	87.4	19.8	5.3	24.4	40.9	9.6	28.6	4,408
Grain mixture[a/]	87.9	21.5	4.4	8.4	59.1	6.6	0.2	4,387
Post-experimental period								
Alfalfa hay	88.4	18.6	2.5	33.6	38.9	6.4	-	4,567
Prairie grass hay	90.9	4.2	1.4	35.0	53.3	6.1	-	4,375
Grain mixture	88.6	22.1	2.3	6.0	61.8	7.8	-	4,152

a/ Approximate formula: 580 lb. cracked corn, 380 lb. wheat bran, 500 lb. crimped oats, 600 lb. 44% soybean oil meal, 100 lb. molasses, 10 lb. dicalcium phosphate, 10 lb. salt, 2 lb. Aurofac A, 2 lb. Quadrex IV, 2 g. cobalt sulfate.

in each group were at various ages between 60 and 90 days. Thus complete data up to 60 days of age were obtained on all of the calves, and complete data up to 90 days of age were obtained on five of the calves in each group. The four experimental-group animals which were younger than 90 days when the experiment ended were moved to elevated stalls at the university calf barn where they were maintained until they reached 90 days of age.

The period lasting from the time the calves were put in the outside pens at 90 days of age until they reached 150 days of age was considered the post-experimental period. The calves were fed in groups in the outside pens during the post-experimental period. They received all the grain they would clean up twice a day plus liberal amounts of alfalfa hay in the morning and prairie grass hay in the afternoon. They were allowed free access to drinking water. The purpose of the post-experimental period was to determine the relative growth of previously heat-stressed and previously non-stressed calves, when both were kept under the same environment. The only data recorded during this period were body weight determinations.

E. Climatic Conditions

Throughout the experimental period an attempt was made to maintain the psychrometric chamber at the schedule of air temperatures and vapor pressures shown in Table 4. The intended schedule was followed reasonably closely, however, the psychrometric chamber occasionally failed to function properly and thus the air temperature and vapor

TABLE 4

Diurnal cycle of air temperature and vapor pressure maintained in the psychrometric chamber

Time	Air temperature	Vapor pressure
	°F	mm. Hg.
6:00 a.m. - 10:00 a.m.	85	20
10:00 a.m. - 4:00 p.m.	95	20
4:00 p.m. - 8:00 p.m.	85	20
8:00 p.m. - 6:00 a.m.	75	20

pressure deviated from the desired levels for several hours. There is also a possibility that air circulation within the chamber was not completely even, as no observations on air velocity at different spots in the chamber were made.

The artificial lights in the psychrometric chamber were turned on between 5:00 a.m. and 6:00 a.m. and off at between 8:00 p.m. and 9:00 p.m. The amount of natural light reaching the calves in the chamber was negligible.

The calves in the control group were subjected to ambient Baton Rouge winter conditions of air temperature and humidity because the university calf barn is closed on only three sides. The calves were protected from inclement weather by a plastic screen extending from the ceiling half way to the floor on the fourth side.

F. Body Weight Determinations

Each calf was weighed on the day of birth and at 30, 60, 90, and 150 days of age, in addition to being weighed every Friday throughout the experimental and post-experimental periods. All weighings subsequent to the weighing at birth were made before grain and hay feeding in the afternoon. Body weights were recorded to the nearest pound. The calves of the two groups were weighed on different scales. The two scales were checked with standard weights and were both found to register the correct weight.

G. Measurements of Rectal Temperature and Respiration Rate

Rectal temperatures and respiration rates were recorded once each week on calves in the control group and three times each week, once at each of the three air temperatures, on calves in the experimental group. These measurements were taken on the control-group calves every Saturday afternoon before grain and hay feeding. They were taken on experimental-group calves Saturday afternoons before the air temperature was changed from 95° to 85°F, Saturday evenings before the air temperature was changed from 85° to 75°F, and Sunday mornings before the air temperature was changed from 75° to 85°F. Rectal temperatures were taken with a clinical thermometer and were recorded to the nearest one-tenth degree Farenheit. Respiration rates were determined by counting flank movements for 30 sec. with the aid of a stop watch and multiplying this value by two to obtain the respiration rate per minute.

H. Blood Analyses

1. Sampling

Blood samples were obtained by jugular puncture every 5 days beginning on December 9, 1961 and continuing until March 29, 1962. A blood sample was drawn from each calf every 5 days from the time it started on the experiment until it reached the age of approximately 8 wk., after which a blood sample was drawn only every 10 days. Thus each calf was sampled 11 times from the time it started on experiment until it reached 60-days of age and three times thereafter until it finished the experiment at 90-days of age, for a total of 14 samplings. Seven of the calves were sampled less than 14 times, however, because the experiment had to be terminated prematurely.

Two samples of blood were drawn at each collection; one was for the purpose of obtaining serum and the other for obtaining plasma. The blood samples were refrigerated for several hours after collection before processing. Serum samples were obtained by means of centrifuging the coagulated whole blood samples. The serum samples were then frozen for subsequent analysis. The blood samples to be used in obtaining plasma were collected using heparin as an anticoagulant. Before being centrifuged, the heparinized whole blood samples were used for hemoglobin and hematocrit determinations. The plasma samples were analyzed during the first 2 or 3 days following each blood collection.

2. Analytical Procedures

a. Hemoglobin and Hematocrit. Hemoglobin content was determined by mixing 0.1 ml. of whole blood with 4.9 ml. of 0.1 N HCL in a Fisher pipette, adding the mixture to a Fisher colorimeter tube, placing the tube in a Fisher electro-hemometer, and reading directly the hemoglobin concentration in grams per 100 ml. of blood.

Hematocrit values were determined by filling a Wintrobe hematocrit tube with whole blood, centrifuging the tube at a centrifugal force of 600 gravities for 30 min., and reading immediately the volume of packed red cells in the tube.

b. Carotenoids and Vitamin A. The plasma samples were utilized for carotenoid and vitamin A analyses by a slight modification of the Kimble procedure (75). The original procedure calls for extraction of 5 ml. of plasma with 10 ml. of petroleum ether B, removing 5 ml. of the supernatant and reading its optical density, using light of wavelength 440 mμ, evaporation of the solution to dryness under a stream of nitrogen, taking up the residue in 1 ml. of chloroform, adding 5 ml. of Carr-Price reagent to develop a blue color, and immediately reading the optical density of the colored solution using light of wavelength 620 mμ. The original procedure was not found to be suitable for analyzing the calf plasma samples because of the low levels of carotenoids and vitamin A contained therein. Thus the original method was modified by extracting 10 ml. of plasma instead of 5 ml. with 10 ml. of petroleum ether B, and by adding 2 ml. of Carr-Price reagent instead of 5 ml. to develop the blue color. Standard solutions were prepared with beta-carotene

and vitamin A acetate for use in constructing the calibration curves. A Bosch and Lomb Spectronic 20 was used in making the optical density readings. The standard emperical correction was made for the interference of carotenoids in the determination of vitamin A concentration. This correction involves subtracting a value equal to carotenoid concentration in mcg. per 100 ml. divided by 20 from the concentration of vitamin A in mcg. per 100 ml. It was decided not to run plasma carotenoid and vitamin A determinations in duplicate because of the large amount of plasma which would have been required at each sampling, the frequency of blood sampling, and the great amount of time required to make the determinations.

c. Serum Proteins. The serum samples were utilized for determinations of serum total protein and of the various serum protein fractions. Serum total protein concentration was determined by a modification of the method of Weichselbaum (134). The procedure involved adding 0.2 ml. of serum to 4.8 ml. of 0.85% aqueous saline solution in a calorimeter tube, adding 5 ml. of biuret reagent, placing the tube in a water bath at 35°C for 30 minutes, and reading the optical density of the solution in a Coleman junior spectrophotometer using light of wavelength 555 mμ. The determinations were run in duplicate. A bovine serum sample known to contain 7.25 g. of protein per 100 ml. was used as the standard.

The serum proteins were electrophoretically fractioned in a Spinco Model R electrophoresis apparatus on paper strips in veronal buffer of pH 8.6 and ionic strength 0.075 under a direct current of

5 milliamps. per cell (eight strips) for 18 hours. The paper strips were then removed from the electrophoresis apparatus and dried in a preheated over (120° to 130°C) for 30 min. Next the paper strips were transferred to a stain-and-rise rack and placed in aqueous bromphenol blue dye for 6 hr. After being removed from the dye, the strips were placed successively in first rinse solution, second rinse solution, and fixative solution, each for 6 min. The first and second rinse solutions consisted of 5% by volume acetic acid in water. The fixative solution contained 9 g. of sodium acetate per liter of 10% acetic acid. Finally the paper strips were dried in a preheated over (115°C) for 30 min. After paper strips had been accumulated for several days they were all scanned in a Spinco Analytrol. The percentage of each protein fraction was calculated from the fraction of the total number of blips, recorded on the lower scale of a Spinco chart sheet 300-542, lying within the pencil lines which were drawn to bound that protein fraction. The proper position of the pencil lines was determined by placing the paper strip next to the curve on the upper scale of the chart sheet and matching the variations in density of the color on the paper strip with the peaks and recesses of the curve. It was assumed that four protein fractions were separated, viz., gamma-, beta-, and alpha-globulins, and albumin. Duplicate determinations were not performed on each sample because there were a large number of samples and only a limited number could be run each day.

I. Digestibility Trial

Individual digestibility trials were performed employing the seven oldest calves in each group. The two youngest calves in each group were not switched from skim milk to water soon enough before the experimental period had to be terminated to make it possible for them to be utilized in the digestibility trial. It was not desired to make digestibility determinations on calves while they were still receiving milk.

Chromic oxide was administered in a gelatin capsule twice a day by balling gun for 5 days of preliminary period and 5 days of feces-collection period. Chromic oxide was given to the experimental-group calves at about 7:00 a.m. and 6:00 p.m. and to the control-group calves at about 6:30 a.m. and 5:30 p.m. In all cases chromic oxide was administered immediately before the calf was given its morning or afternoon water allowance. This procedure was followed to help prevent the calf from regurgitating the gelatin capsule. The first six calves to be placed on digestion trial were given a total of 5 g. of chromic oxide per day and the remaining eight animals were given a total of 4 g. of chromic oxide per day.

Grab fecal samples were collected from the experimental-group calves at about 5:30 a.m. and 6:00 p.m. and from the control-group calves at about 6:00 a.m. and 5:30 p.m. The samples were placed in plastic bags and frozen for subsequent analysis. Samples of grain and hay fed and refused were collected each day beginning one day prior to the start of the feces-collection period and

continuing until the 4th day of the feces collection period. The feed samples were placed in paper bags and stored for subsequent chemical analysis.

When ready for analysis, the fecal samples were first thawed in the plastic bags. Each sample was mixed as well as possible by squeezing the bag before opening it. An equal amount by volume was withdrawn from each of the 10 samples for each animal and placed on a previously-weighed aluminum tray. The dry matter content was determined by weighing the wet composite fecal sample, drying it at 75°C for 36 hr. and re-weighing. The dried composite fecal sample was then coarsely ground and subjected to proximate analysis by the standard A.O.A.C. procedure (5).

Part of each of the dried composite fecal samples was ground to pass a 40-mesh screen and then subjected to chromic oxide analysis by the method of Kimura and Miller (76). Duplicate determinations were performed on each sample.

The dried composite fecal samples remaining after the chromic oxide determinations were ground to pass a 60-mesh screen and were then used for heat of combustion determinations. Heat of combustion or gross energy was determined using a Parr Seris 1300 plain jacket oxygen bomb calorimeter. In preliminary work it was found to be extremely difficult to obtain complete combustion when igniting the fecal samples alone. Therefore, a benzoic acid primer was used to ensure complete combustion. One-half gram of over-dry feces was mixed with 0.5 g. of benzoic acid and the mixture was compressed into

a pellet in a Parr pellet press. The combustion and calculation of results were carried out according to the directions supplied by the manufacturer (100). The known amount of heat liberated by combustion of the primer was subtracted from the total amount of heat liberated to determine the amount of heat liberated by combustion of the sample. A correction was also made for the chromic oxide content of the fecal sample by subtracting it in arriving at the weight of fecal sample combusted. The complete analysis of the composite fecal samples is given in Appendix Table 1a.

The feed samples and the feed-refusal samples collected during the digestion trial for each calf were composited and coarsely ground. The samples were subjected to proximate analysis and gross energy determinations by the same procedures used on the fecal samples, except that no primer was used along with the samples in the bomb calorimeter. Gross energies were determined on oven-dry samples after they had been ground to pass a 40-mesh screen. The complete analyses of the composite feed and feed-refusal samples are given in Appendix Tables 2a to 5a.

The average daily dry matter consumption of each calf during the digestion trial was calculated from the feed consumption data beginning on the 2nd day before the start of the feces collection period and continuing until the 4th day of the feces collection period. The average daily intake of each feed constituent under consideration was calculated as the total amount of that constituent fed minus the amount present in the feed which the animal refused.

The average daily feces dry matter production of each animal during the digestion trial was calculated by dividing the amount of chromic oxide administered daily by the concentration of chromic oxide present in the dry matter of the composite fecal sample. The average daily amount of each feed constituent under consideration voided in the feces was then calculated from the chemical composition of the feces. The data obtained from the digestion trial were used to calculate digestion coefficients of dry matter, crude protein, total nutrients, and gross energy.

J. Statistical Analyses

Included in the data were 22 Y variables and three X variables. The Y variables were as follows: Y_1 = hematocrit value, Y_2 = blood hemoglobin level, Y_3 = plasma carotenoid level, Y_4 = plasma vitamin A level, Y_5 = serum total protein level, Y_6 = serum gamma-globulin level, Y_7 = serum beta-globulin level, Y_8 = serum alpha-globulin level, Y_9 = serum albumin level, Y_{10} = serum albumin/globulin ratio, Y_{11} = daily whole milk intake, Y_{12} = daily skim milk intake, Y_{13} = daily grain dry matter intake, Y_{14} = daily hay dry matter intake, Y_{15} = daily total (grain plus hay) dry matter intake, Y_{16} = body weight gain, Y_{17} = respiration rate at 95°F, Y_{18} - respiration rate at 85°F, Y_{19} = respiration rate at 75°F, Y_{20} = rectal temperature at 95°F, Y_{21} = rectal temperature at 85°F, and Y_{22} = rectal temperature at 75°F. The X variables were as follows: X_1 = age in days, X_2 = daily carotenoid intake, X_3 = daily protein intake.

The over-all experimental period for each calf was considered to consist of three experimental periods. Period I lasted from the time the calf started on the experiment until 30-days of age, period II from 31- to 60-days of age, and period III from 61- to 90-days of age. Variables Y_1 through Y_{10} were recorded for 5-day intervals during periods I and II and for 10-day intervals during period III. Variables Y_{11} through Y_{22} were recorded for 7-day intervals throughout the experimental period. On the former set of variables, five observations were obtained in period I, six observations in period II, and three observations in period III, for a total of 14 observations. On the latter set of variables, four observations were obtained in each of the three periods for a total of 12 observations. Due to the premature termination of the experiment, less than three observations were obtained in period III on the former set of variables and less than four observations were obtained in period III on the latter set of variables in seven of the 18 calves.

Since respiration rates and rectal temperatures were taken only once a week in the control-group calves, the data for variables Y_{17}, Y_{18}, and Y_{19} and for variables Y_{20}, Y_{21}, and Y_{22} were identical in this group. Daily carotenoid intake, X_2, was taken as the average for the five days preceding the day of each blood collection. Figures on carotenoid contents were available for the grain and hay. Whole milk was assigned a carotenoid equivalent of 2.0 mg./lb. based on its carotene and vitamin A contents as given by Morrison (92). Allowance was made for the fact that a unit of vitamin A is approximately four times more potent than a unit of carotene in the bovine.

Skim milk was assumed not to contain any significant amount of vitamin A or carotene. Daily protein intake, X_3, was also taken as the average for the five days preceding the day of each blood collection. Figures on protein contents were available for the grain and hay, whereas estimates of the protein contents of whole milk and skim milk were obtained from the tables of Morrison.

The data were punched on IBM cards for analysis using the 1620 computer of the L.S.U. Computer Research Center.

A three-factor analysis of variance was performed on each of the 22 Y variables in each experimental period, except on Y_{11} in periods II and III or Y_{12} in period III, for which there were no data. The three factors were groups, animals, and sexes. Variances were calculated for between groups, between sexes, group x sex interaction, among animals within-sex, within-group, and residual. In testing the significance on these variances, group and sex were considered to be fixed effects.

An analogous three-factor analysis of covariance was performed on seven of the Y variables in each experimental period. The covariance analyses were Y_3 adjusted for X_2, Y_4 adjusted for X_2, Y_5 adjusted for X_3, Y_6 adjusted for Y_5, Y_7 adjusted for Y_5, Y_8 adjusted for Y_5, and Y_9 adjusted for Y_5. Adjusted variances were calculated for between groups, between sexes, group X sex interaction, among animals within-sex, within-group, and residual.

Within-group multiple regression analyses over all three experimental periods were performed on each of the variables Y_1 through

Y_{10} and Y_{13} through Y_{22}. In these analyses the X variable was X_1. First a cubic equation was fitted, and if the cubic term was significant, the cubic equation was accepted as the prediction equation. If the cubic term was not significant, it was deleted and a quadratic equation was fitted. If the quadratic term was significant, the quadratic equation was accepted as the prediction equation, but if the quadratic term was not significant, it was deleted and a linear equation was fitted. The square of the coefficient of multiple correlation (R^2) was also obtained from the analysis of each dependent variable. This statistic indicates the per cent of the variability in the dependent variable (Y) which can be explained by the effect of age (X) and X^2 and X^3 in cases where these terms were used.

A two-factor analysis of variance was performed on each of the variables gain in weight from 90 to 150 days of age, dry matter digestibility, crude protein digestibility, total digestible nutrients, and energy digestibility. The two factors were groups and sexes. Variances were calculated for between groups, between sexes, group x sex interaction, and residual. In testing the significance of these variances, group and sex were considered to be fixed effects. The facilities of the Computer Research Center were not used in performing the two-factor analyses of variance.

RESULTS AND DISCUSSION

A. Body Weight Gains

The average daily body weight gains of the calves in both groups for each of the three experimental periods and the post-experimental period are presented in Table 5 and Appendix Table 6a. The analyses of variances of the body weight gain data are presented in Appendix Table 15a.

A plot of the prediction equations showing the age trend in body weight gain for each group is presented in Figure 1. A semi-logarithmic plot of body weight vs. age throughout the experimental and post-experimental periods is presented in Figure 1a.

The average daily body weight gains of the control-group and experimental-group calves in periods I, II, III, and the post-experimental period were 0.74 and 0.56, 1.19 and 0.74, 1.50 and 0.56, and 0.94 and 0.64 lb., respectively. The between-group differences were nonsignificant in period I, but highly significant ($P < 0.01$) in periods II, III, and in the post-experimental period. The average daily body weight gain of the control-group calves increased from period I to period II and again from period II to period III, whereas the average daily gain of the experimental-group calves increased slightly from period I to period II, but then declined again from period II to period III In Figure 1, it appears that the rate of

TABLE 5

Average Daily Body Weight Gains of the Calves

	Period I	Period II	Period III	Post-experimental period
	(lb.)			
Control group means				
Females	0.86	1.17	1.50	0.92
Males	0.61	1.21	1.49	0.97
Experimental group means				
Females	0.46	0.71	0.41	0.56
Males	0.69	0.77	0.77	0.75
Females, mean	0.66	0.94	0.94	0.74
Males, mean	0.66	1.00	1.14	0.86
Control group mean	0.74	1.19	1.50	0.94
Experimental group mean	0.56	0.74	0.56	0.64
Over-all mean	0.66	0.97	1.03	0.79

gain of the experimental-group calves was finally beginning to pick up again near the end of the experimental period. In the semi-logarithmic plot of body weight vs. age (Figure 1a), the control-group calves showed a decrease in the first week of life and a recovery in the second week, then a nearly linear increase throughout the rest of the experimental period (except for an unexplainable decrease at 12 wk of age), then another nearly linear, though less steep, increase throughout the post-experimental period. The experimental-group calves did not show a linear increase in the semi-logarithmic plot

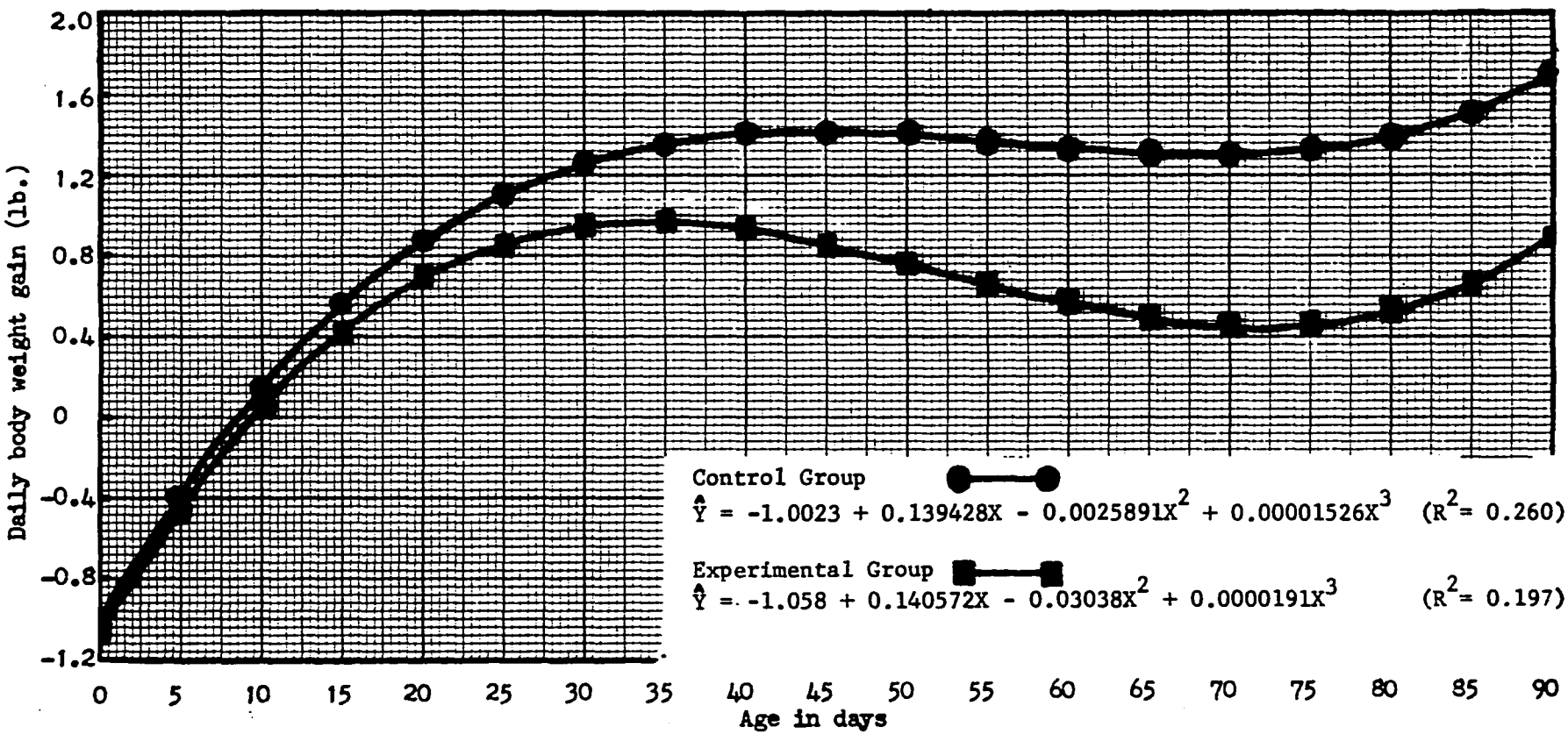

Figure 1. Within-group prediction equations for daily body weight gain vs. age

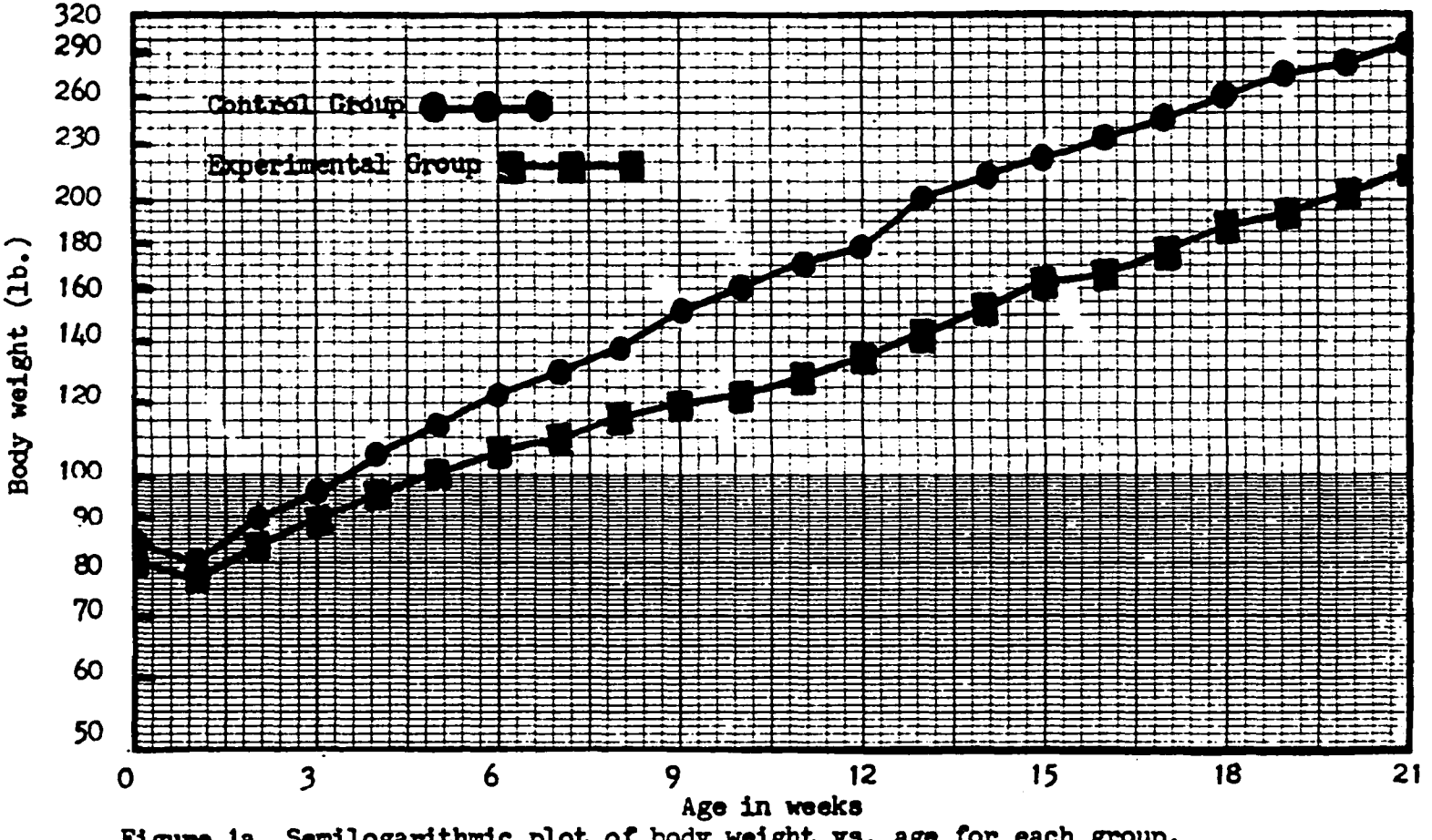

Figure 1a. Semilogarithmic plot of body weight vs. age for each group.

of body weight vs. age during the experimental period or during the early part of the post-experimental period, but they did appear to be finally showing a linear increase during the latter part of the post-experimental period. The control-group calves grew more slowly during the post-experimental period than they had during the experimental periods II or III, while the experimental-group calves grew more rapidly during the post-experimental period than they had during experimental period III, but more slowly than they had during experimental period II. The low average daily weight gains of calves 478-1, 639, and 502-1 during period I (Appendix Table 6a) were due to sickness of these calves, viz., respiratory infection in the former case and scours in the latter two cases. The low average daily weight gain of calf 640 during period III was based on only one week's observation and is not indicative of the growth which this calf was making at that stage. Two of the experimental-group calves, 635 and 637, made very poor gains in the post-experimental period. These two calves were extremely weak and had to be put back into individual stalls to insure their survival. The average growth rate of the male calves was greater than that of the female calves, though not significantly so, in all except period I.

The severe retardation of growth was the most obvious and most important effect of heat exposure upon the experimental-group calves. The manner in which this retardation of growth developed is interesting. During period I, which represented the whole milk-feeding period and the start of the skim milk feeding period, the heat-stressed calves were not at a significant disadvantage in growth rate relative to the non-stressed calves. During period II which

represented the remainder of the skim milk-feeding period and during period III when no milk was fed, the heat-stressed calves could no longer keep pace in growth rate with the non-stressed calves. Perhaps a longer whole milk-feeding period would have reduced the difference between the growth rates of the two groups. Johnson and Ragsdale (57) showed that a constant environmental temperature of 80°F was moderately stressful to young Holstein calves and caused some depression of growth rate. The present study has shown that a regimen of environmental temperatures cycling from 75° to 95°F is decidedly stressful to young Holstein calves and produces a greatly depressed growth rate.

It should be noted (Appendix Table 6a) that considerable individual variation existed in the responses of the experimental-group calves to hot conditions. Calves 635 and 637 were very severely affected and had practically stopped growing at 90 days of age. Calves 634, 639, and 502-1 continued to grow throughout the experimental period, but at a slow rate. Calf 446-1 gained well during experimental period I, but his growth rate declined after being taken off whole milk. Calves 632 and 438-1 made fair gains throughout the experimental period. These calves did not appear to be unduly uncomfortable in spite of the hot condition. Calf 75-3 appeared to be affected very little either in growth rate or in visible signs of discomfort by the hot conditions. Though this calf showed high respiration rates (Appendix Table 9a), his rectal temperature was consistently lower than those of the other calves

in the experimental group (Appendix Table 10a). It is noteworthy that this calf had the sleekest hair-coat of any of the experimental-group calves. Most of the other calves of this group had rough hair-coats. Yeates (139) also found one smooth-coated heifer, possessing superior heat tolerance, in a group of wooly-coated Poll Shorthorn cattle. There was individual variation in the growth rates of the control-group calves also, but only Calf 531-1 of this group showed a poor growth rate.

It had been anticipated that the retarded experimental-group calves would recover and make accelerated growth during the post-experimental period; however, the reverse situation occurred. The growth rates of the experimental-group calves continued to be lower than those of the control-group calves. Apparently the experimental-group calves required longer than two months to recover from the adverse effects of the previous heat exposure. This finding further emphasizes the importance of protecting young calves from heat stress under practical husbandry conditions. The drop in growth rates of the control-group calves from experimental period III to the post-experimental period undoubtedly reflects the favorable effect of individual care and feeding which the calves received during the experimental, but not during the post-experimental period.

B. Feed Consumption

1. Whole Milk and Skim Milk Intakes

The average daily whole milk and skim milk intake of the calves in both groups for experimental periods I and II are given

in Table 6, and the analyses of variance of the whole milk and skim milk intake data are given in Appendix Table 16a.

TABLE 6

Average daily whole milk and skim milk intakes of the calves

	Period I		Period II
	Whole milk	Skim milk	Skim milk
	(lb.)		
Control group means			
Females	4.63	2.11	10.19
Males	4.57	2.16	10.32
Experimental group means			
Females	4.43	2.63	10.44
Males	4.91	2.08	10.14
Females, mean	4.53	2.37	10.31
Males, mean	4.74	2.12	10.23
Control group mean	4.60	2.13	10.25
Experimental group mean	4.64	2.39	10.30
Over-all mean	4.62	2.26	10.28

The average daily whole milk intakes of the control-group and experimental-group calves in period I were 4.60 and 4.64 lb., respectively. The average daily skim milk intakes of the control-group and experimental-group calves in periods I and II were 2.13 and 2.39, and 10.25 and 10.30 lb., respectively. None of these differences between groups were significant. The differences between sexes and among animals within-sex, within-group, and the group x sex interaction were also nonsignificant in both periods. This is in agreement with the design of the experiment in which whole milk and skim milk feeding were to be equalized among all calves.

2. Grain, Hay, and Total Dry Matter Intakes

The average daily grain, hay, and total dry matter intakes of the calves in both groups for each of the three experimental periods are presented in Table 7 and Appendix Table 7a. The analyses of variance of the grain, hay, and total dry matter intake data are presented in Appendix Tables 17a, 18a, and 19a, respectively. Plots of the prediction equations showing the age trends in daily grain, hay, and total dry matter intake for each group are given in Figures 2, 3, and 4, respectively.

The average daily grain dry matter intakes of the control-group and experimental-group calves in periods I, II, and III were 0.48 and 0.19, 1.30 and 0.43, and 3.36 and 1.70 lb., respectively. The between-group differences were significant ($P < 0.05$) in period I, and highly significant ($P < 0.01$) in periods II and III. In both groups there was a steady increase in grain dry matter intake throughout the experimental period, as shown in Figure 2. However, the intakes of the control-group calves were two to three times as great as those of the experimental-group calves. In none of the three experimental periods was the grain dry matter intake of any calf of the experimental group as great as the average grain dry matter intake of the control-group calves.

The average daily hay dry matter intakes of the control-group and experimental-group calves in periods I, II, and III were 0.07 and 0.03, 0.54 and 0.24, and 1.18 and 0.73 lb., respectively. The between-group difference was significant ($P < 0.05$) in period II, and

TABLE 7

Average daily grain, hay, and total dry matter intakes of the calves

	Period I			Period II			Period III		
	Grain	Hay	Total	Grain	Hay	Total	Grain	Hay	Total
	(lb.)								
Control group means									
Females	0.51	0.08	0.59	1.27	0.53	1.80	3.39	1.27	4.65
Males	0.44	0.06	0.51	1.33	0.56	1.89	3.33	1.08	4.41
Experimental group means									
Females	0.22	0.04	0.26	0.47	0.23	0.70	1.79	0.55	2.34
Males	0.16	0.01	0.17	0.39	0.26	0.65	1.56	0.99	2.46
Females, mean	0.36	0.06	0.42	0,87	0.38	1.25	2.56	0.90	3.46
Males, mean	0.30	0.04	0.34	0.86	0.41	1.27	2.49	1.03	3.48
Control group mean	0.48	0.07	0.55	1.30	0.54	1.84	3.36	1.18	4.54
Experimental group mean	0.19	0.03	0.22	0.43	0.24	0.68	1.70	0.73	2.39
Over-all mean	0.33	0.05	0.38	0.87	0.39	1.26	2.53	0.96	3.47

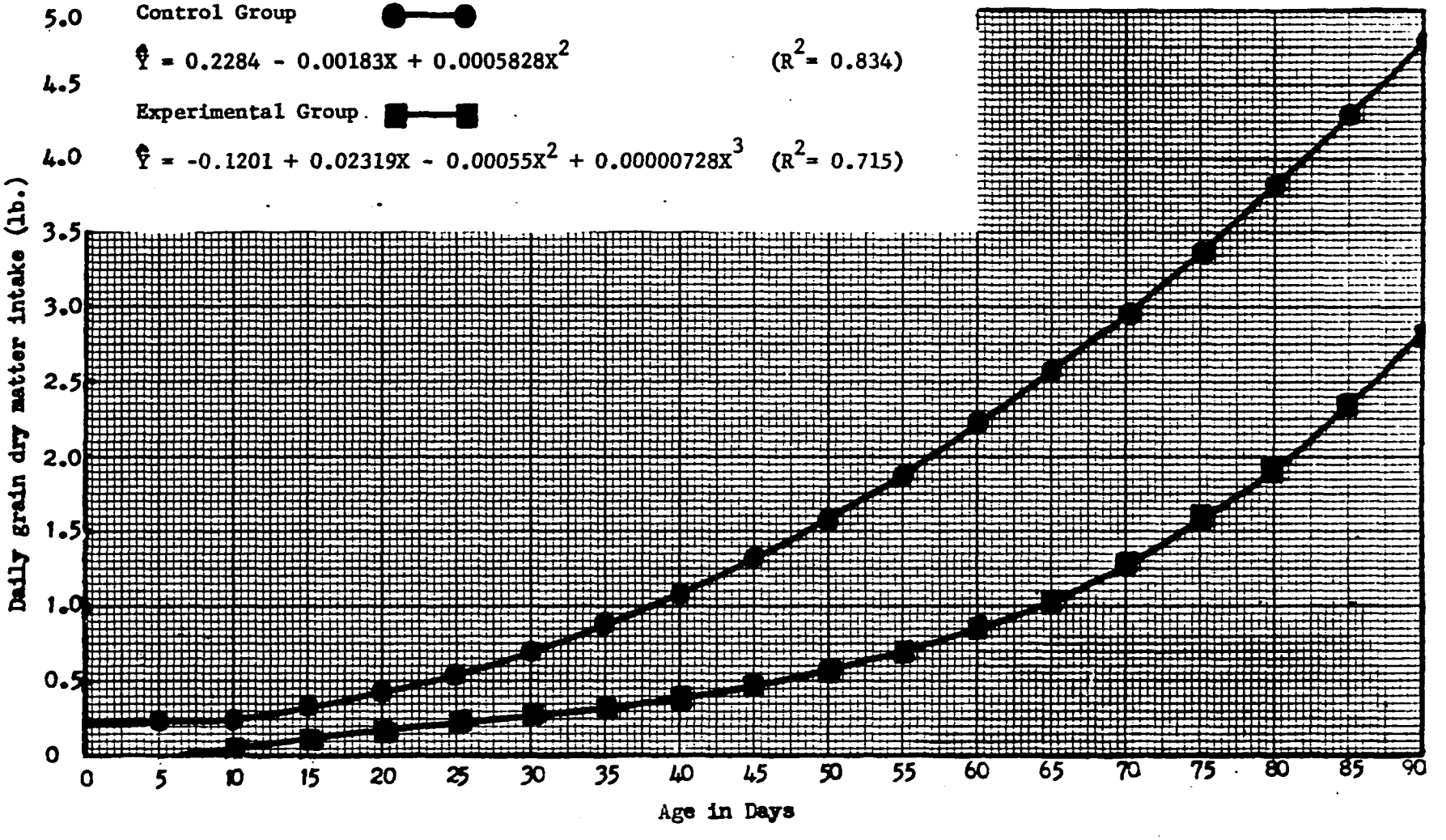

Figure 2. Within-group prediction equations for grain dry matter intake vs. age.

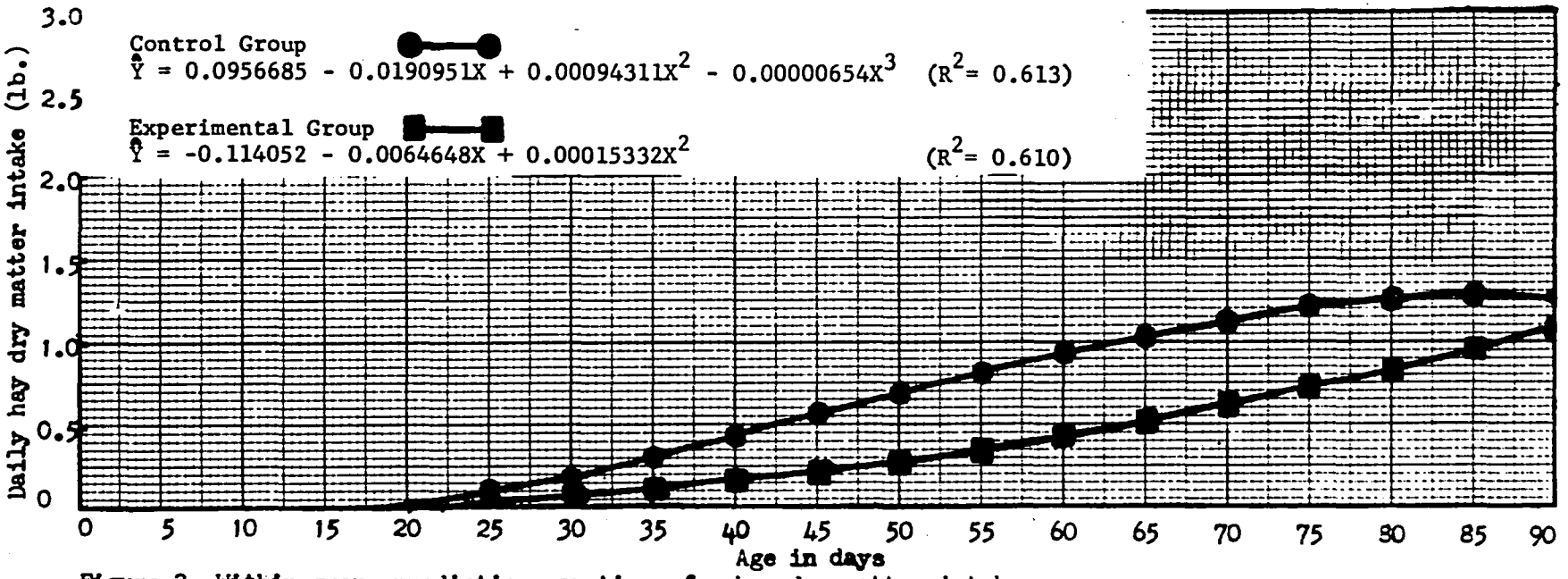

Figure 3. Within-group prediction equations for hay dry matter intake vs. age

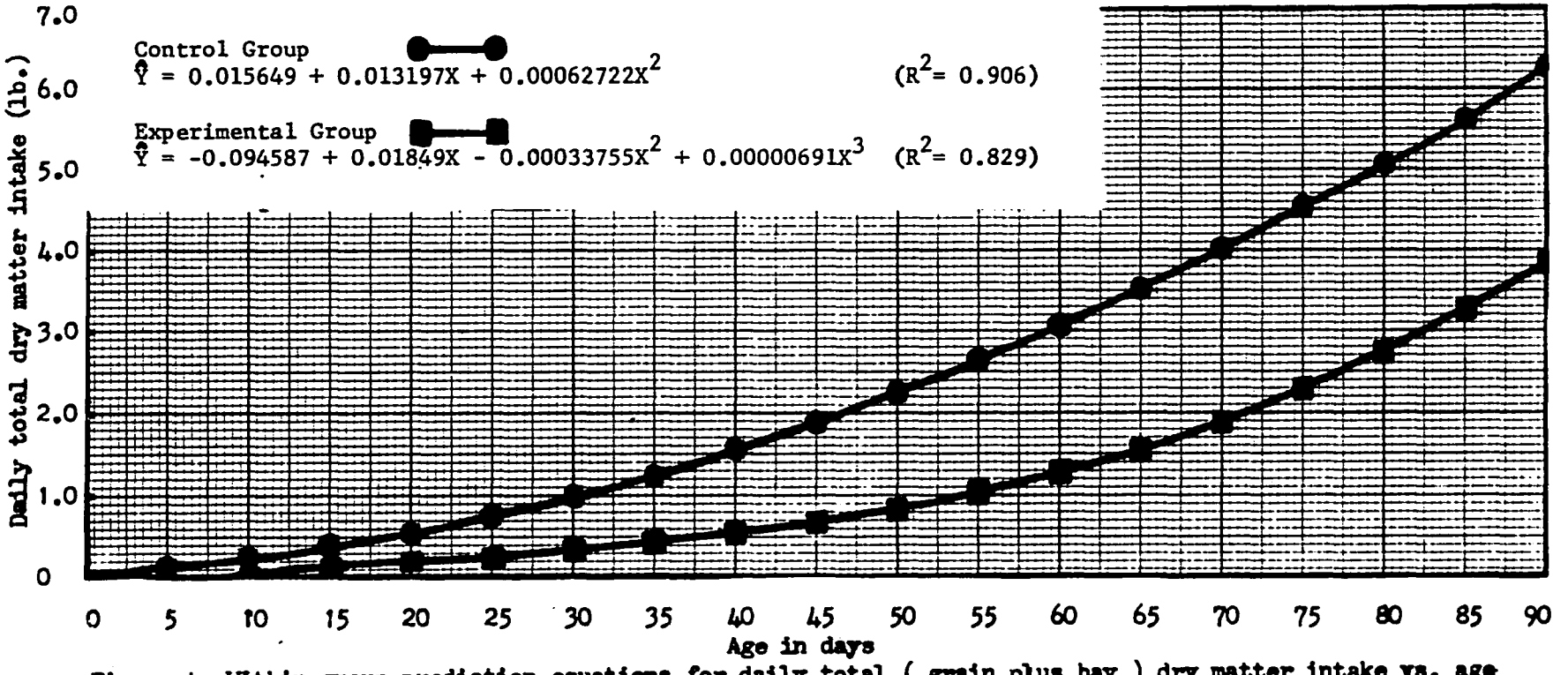

Figure 4. Within-group prediction equations for daily total (grain plus hay) dry matter intake vs. age

it approached significance in period III. Hay intake was negligible in period I, except in three calves of the control group which consumed small amounts. Though all of the calves showed increases in hay dry matter consumption with age, the figures for three control-group and seven experimental-group calves never reached as high as 1 lb. per day. In general, the calves of both groups consumed much less hay than they did grain.

The average daily total dry matter intakes (grain plus hay) of the control-group and experimental-group calves in periods I, II, and III were 0.55 and 0.22, 1.84 and 0.68, and 4.54 and 2.39 lb., respectively. The between group differences were significant ($P < 0.05$) in period I and highly significant ($P < 0.01$) in periods II and III.

The reduced growth rate of the experimental-group calves, especially in experimental periods II and III, can readily be explained by consideration of the feed consumption data of Table 7 and Appendix Table 7a. The calves of both groups consumed only small amounts of grain and hay while consuming whole milk in period I, and it was during this period that their growth rates did not differ significantly. In period II, when skim milk was being consumed, the control-group calves consumed nearly 2 lb. dry matter from grain and hay daily, while the experimental-group calves consumed only slightly over 0.5 lb. Consumption of grain and hay increased greatly in period III when the calves no longer were consuming any milk, with the control-group calves consuming about 4.5 lb. and the

experimental-group calves about 2.4 lb. total dry matter daily. There seems little doubt that the hot conditions exerted an effect on the hypothalamic food-intake-regulating centers of the experimental-group calves, either directly or indirectly, to decrease feed consumption of the experimental-group calves.

Johnson et al. (60) also found that continuous exposure to hot conditions reduced the TDN consumption of Holstein calves during the second and third months of life. The reduction in feed consumption was more marked in the present experiment, which is consistent with the fact that the heat stress was more severe.

C. Digestibility

The chemical analyses of the composite feces samples collected during the digestion trials and of the grain and hay fed and refused during the trials are presented in Appendix Tables 1a to 5a. The digestibility coefficients for dry matter, crude protein, total nutrients, and energy are presented in Table 8 and Appendix Table 8a. The analyses of variance of the digestibility data are presented in Appendix Table 20a.

The means of the digestibility coefficients found in the control-group and experimental-group calves were 69.43 and 66.13 for dry matter, 72.08 and 68.67 for crude protein, 70.43 and 66.60 for total nutrients, and 67.48 and 63.04 for energy, respectively. None of the between-group differences were significant. The only significant result found in the analyses of the digestibility coefficients was a significant group x sex interaction ($P < 0.05$) in

TABLE 8

Coefficients of digestibility determined during the digestion trials of period III

	Digestibility coefficient			
	Dry matter	Crude protein	Total nutrients	Energy
	(%)			
Control group means				
Females	69.90	73.40	70.98	68.15
Males	68.81	70.32	69.69	66.58
Experimental group means				
Females	63.01	65.33	63.30	59.07
Males	70.28	73.12	71.01	68.33
Females, mean	66.45	69.37	67.14	63.61
Males, mean	69.55	71.72	70.35	67.46
Control group mean	69.43	72.08	70.43	67.48
Experimental group mean	66.13	68.67	66.60	63.04
Over-all mean	67.78	70.38	68.51	65.26

the case of digestible energy. In general there was not much variability in the digestibility coefficients. Inspection of the figures in Appendix Tables 4a and 5a reveals that the hay refused by the calves of both groups tended to be higher in crude protein and lower in crude fiber than the hay fed, which was due to the fact that most of the calves selectively ate the stems rather than the leaves of the alfalfa hay offered them. The grain refused by the calves also tended to be slightly higher in crude protein than the grain fed, as seen in Appendix Tables 2a and 3a, but the reason for this is not immediately apparent.

The finding that digestibility coefficients for dry matter, crude protein, total nutrients, and energy were all slightly lower in the calves under hot conditions than in the calves under cool conditions is contrary to other reports, in which cattle under hot conditions showed reduced feed consumption but slightly increased digestibility (31, 42, 62, 65, 66). Though the decreases in digestibility coefficients in the heat-stressed calves of the present study were not statistically significant, the magnitude of the decreases might have been greater if the heat-stressed calves had not been on a voluntarily lower plane of nutrition than the non-stressed calves, thus there was some indication that heat-stress had an adverse effect on the digestive process. Another possible explanation for the lower apparent digestive efficiency in the experimental-group calves is that these calves had not yet consumed any great amount of solid feed, so that their rumina were not yet fully functional, whereas rumen function was developed to a greater extent in the control-group calves, which had previously consumed more solid feed. If this is the correct interpretation, then the exposure to heat had an indirect rather than a direct effect upon digestive efficiency. Nevertheless, it is not possible to discount the possibility that heat exposure did have some direct effect in reducing digestive efficiency under the conditions of this study. Obviously, more digestibility trials, especially trials utilizing equal planes of nutrition, in young calves under hot and cool conditions are needed to clarify this point.

D. Respiration Rate and Rectal Temperature

The average respiration rates and rectal temperature of the control-group calves at ambient temperature and of the experimental-group calves at each of the three air temperatures for each of the three experimental periods are presented in Tables 9 and 10, and Appendix Tables 9a and 10a, respectively. The analyses of variance of the respiration rate and rectal temperature data are presented in Appendix Tables 21a and 22a, respectively. Plots of the prediction equations showing the age trends in respiration rate and rectal temperature are presented in Figures 5 and 6, respectively.

The average respiration rates per minute of the control-group calves in periods I, II, and III were 34.3, 43.8, and 53.0, respectively. The average respiration rates per minute of the experimental-group calves at air temperatures of 95°, 85°, and 75°F were respectively 93.4, 75.9, and 44.0 in period I, 100.8, 86.9, and 62.2 in period II, and 96.7, 85.0, and 65.1 in period III. The differences between the respiration rates of the experimental-group calves at 95° and 85°F air temperatures and of the control-group calves at ambient temperature were highly significant ($P < 0.01$) in all three periods. The differences between the respiration rates of the experimental-group calves at 75°F air temperature and of the control-group calves at ambient temperature were highly significant ($P < 0.01$) in periods I and II, but nonsignificant in period III. The respiration rates in the control-group calves and in the experimental-group calves at 75° and 85°F air temperatures increased throughout the experimental

TABLE 9

Average respiration rates of the calves at various air temperatures (°F)[a/]

	Period I			Period II			Period III		
	95°	85°	75°	95°	85°	75°	95°	85°	75°
	(respirations/min.)								
Control group means									
Females	38.3	-	-	41.5	-	-	58.0	-	-
Males	29.4	-	-	46.6	-	-	46.8	-	-
Experimental group means									
Females	98.4	71.7	44.5	99.8	90.0	67.2	90.3	82.1	64.5
Males	91.6	81.2	43.3	102.1	83.0	56.0	106.1	89.2	65.9
Females, mean	66.5	55.0	41.4	70.7	65.8	54.4	74.6	70.5	61.4
Males, mean	60.5	53.0	36.4	74.3	64.8	51.3	75.2	67.1	56.0
Control group mean	34.3	-	-	43.8	-	-	53.0	-	-
Experimental group mean	93.4	75.9	44.0	100.8	86.9	62.2	96.7	85.0	65.1
Over-all mean	63.8	55.1	39.2	72.3	65.3	53.0	74.9	69.0	59.1

a/ Observations on the control-group calves were made at ambient air temperature.

TABLE 10

Average rectal temperatures of the calves at various air temperatures (°F)[a/]

	Period I			Period II			Period III		
	95°	85°	75°	95°	85°	75°	95°	85°	75°
	(°F)								
Control group means									
Females	102.9	-	-	102.8	-	-	103.1	-	-
Males	102.6	-	-	103.2	-	-	103.0	-	-
Experimental group mean									
Females	104.8	104.2	103.8	105.2	105.1	104.1	105.5	105.4	104.3
Males	104.4	104.3	103.6	104.6	104.6	103.5	105.0	105.0	104.0
Females, mean	103.9	103.6	103.6	104.0	104.0	103.5	104.4	104.3	103.7
Males, mean	103.5	103.4	103.1	103.9	103.9	103.3	104.0	104.0	103.5
Control group mean	102.8	-	-	103.0	-	-	103.1	-	-
Experimental group mean	104.6	104.3	103.7	104.9	104.9	103.8	105.3	105.2	104.2
Over-all mean	103.7	103.5	103.2	104.0	103.9	103.4	104.2	104.2	103.6

a/ Observations on the control-group calves were made at ambient air temperature.

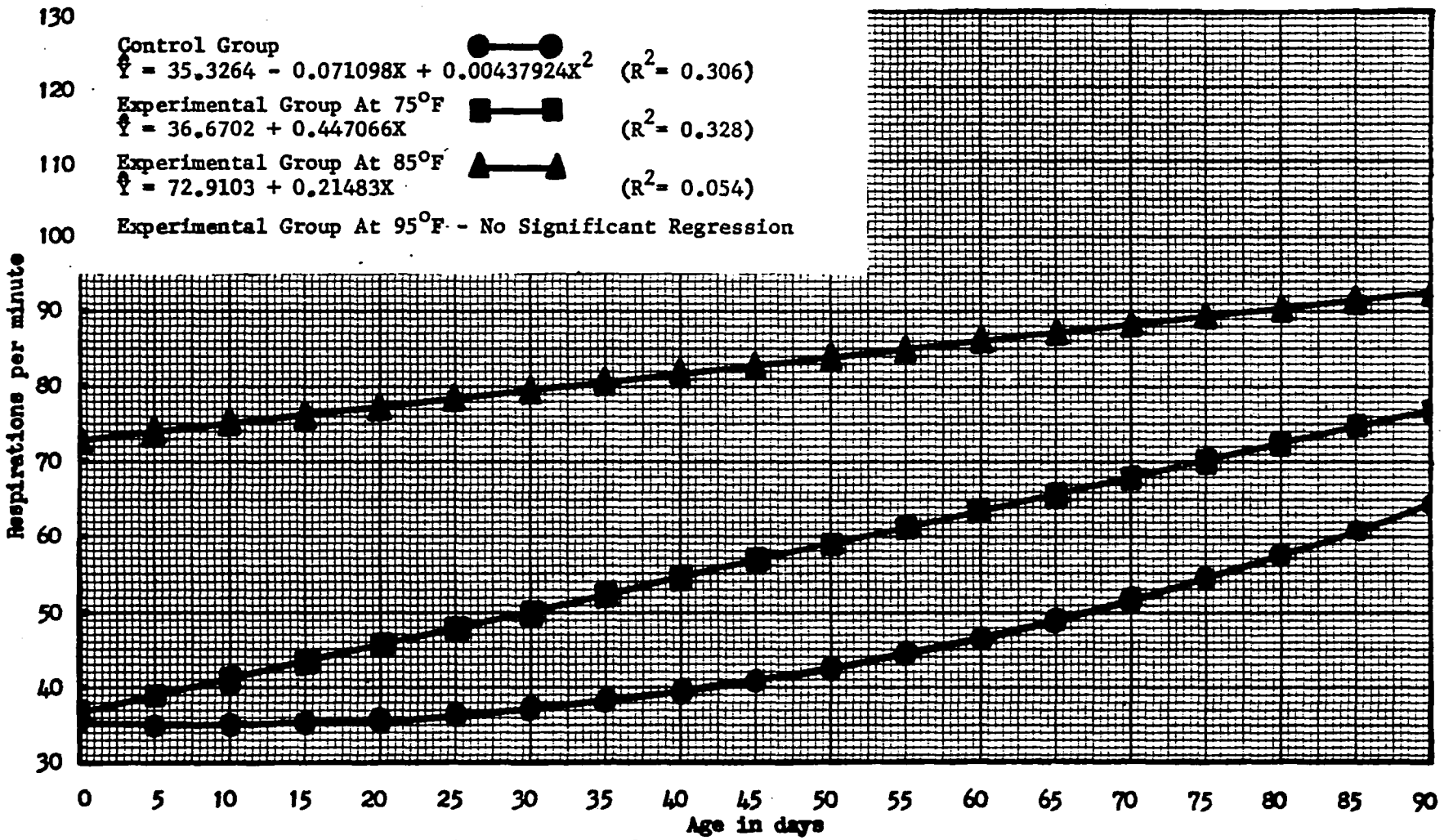

Figure 5. Within-group prediction equations for respiration rate vs. age

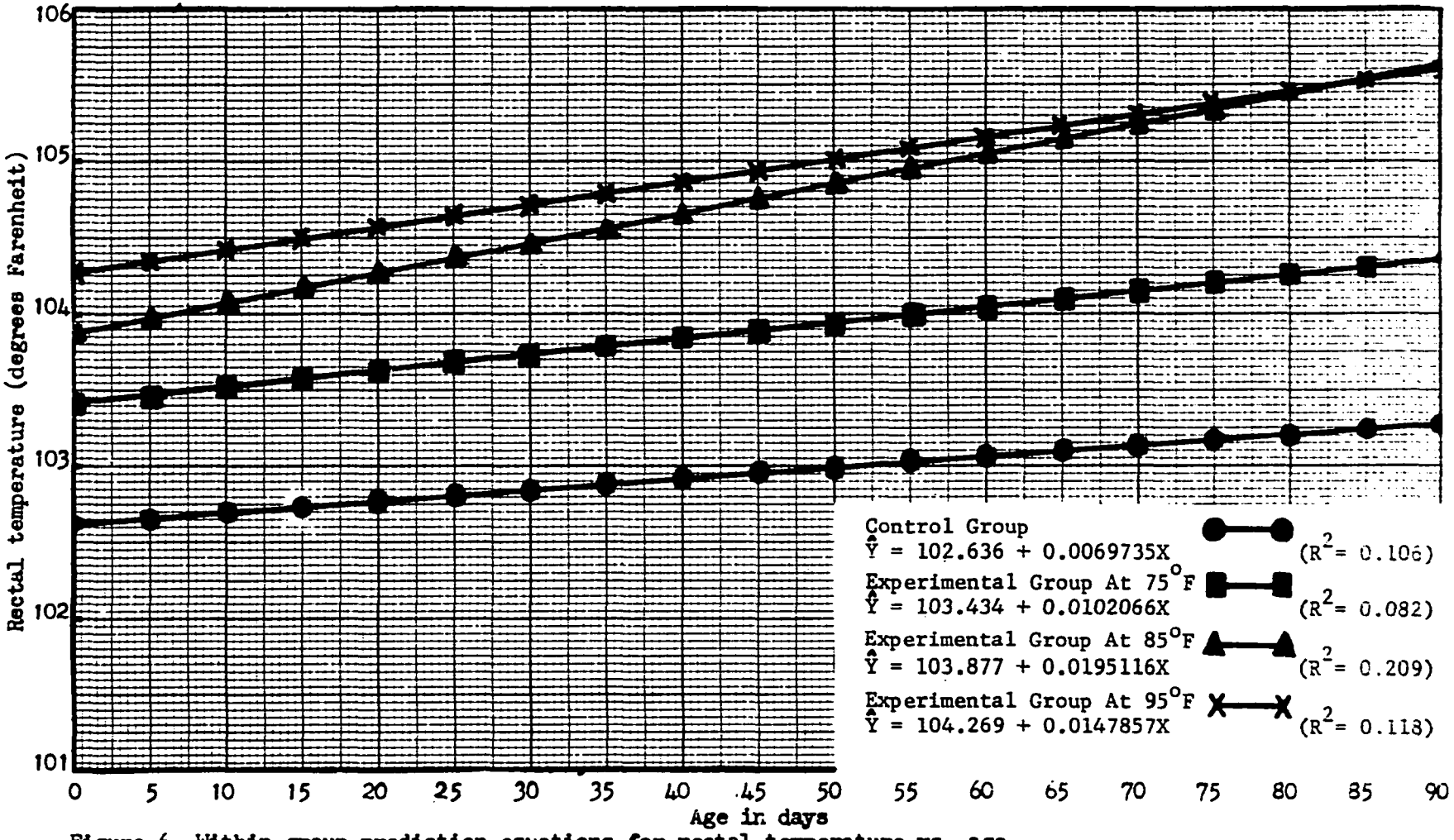

Figure 6. Within-group prediction equations for rectal temperature vs. age

period, as shown in Figure 5. The increase in respiration rate of the experimental-group calves at 85°F with age was very erratic as shown by the low R^2 value of 0.054. There was no consistent change in the respiration rates of the experimental-group calves at 95°F air temperature with age. The increased respiration rate with age in the control-group calves and in the experimental-group calves at the two lower air temperatures may have been due to the possibility that the calves had more heat per unit surface area to dissipate as they became older. The experimental-group calves at 95°F air temperature may have been breathing too rapidly right from the start of the experimental period to be able to increase their rate of breathing very much. The fact that the rate of increase in respiration rate with age in the experimental-group calves was greater at 75°F than at 85°F, is not inconsistent with this line of reasoning.

The average rectal temperatures of the control-group calves in periods I, II, and III were 102.8°, 103.0°, and 103.1°F, respectively. These figures are rather high in comparison to the body temperatures which are usually considered normal for the bovine. However, Wrenn (138) also found that calves exhibit high body temperatures. The average rectal temperatures of the experimental-group calves at 95°, 85°, and 75°F air temperatures were, respectively, 104.6°, 104.3°, and 103.7°F in period I, 104.9°, 104.9°, and 103.8°F in period II, and 105.3°, 105.2°, and 104.2°F in period III. The differences between the rectal temperatures of the experimental-group calves at all three air temperatures and of the control-group calves at ambient temperature were highly significant ($P < 0.01$) in all three periods. The rectal temperatures in the control-group calves and in

the experimental-group calves at all three air temperatures increased throughout the experiment period, as shown in Figure 6. The increases in rectal temperature with age were rather erratic, as shown by the low R^2 values for three of the four regressions. It can be surmised that the increase in rectal temperatures with age was due to increasing metabolic and ruminal heat production without corresponding increases in heat dissipation as the calves became older. The rate of increase in rectal temperature with age in the experimental-group calves was greatest at 85°, next at 95°, and least at 75°F air temperature. The average rectal temperatures of the experimental-group calves at 85°F were nearly as high as those at 95°F in experimental periods II and III.

Inspection of the respiration rate and rectal temperature data of the individual calves in Appendix Tables 9a and 10a leaves little doubt that the experimental-group calves were subjected to thermally stressful conditions. The respiration rates per minute of the experimental-group calves at 95°, 85°, and 75°F air temperatures were mostly within the ranges 80 to 120, 65 to 110, and 40 to 75, respectively, while those of the control-group calves were usually between 30 and 60. The rectal temperatures of the experimental-group calves (with the exception of calf 75-3) at 95°, 85°, and 75°F air temperatures fell mainly within the ranges 104.0° to 106.0°, 103.5° to 106.0°, and 103.0° to 104.5°F, respectively, while those of the control-group calves generally ranged from 102.5° to 103.5°F.

The fact that respiration rates followed fluctuations in air temperature more closely than did rectal temperatures is not surprising. There is a considerable time lag in the response of body temperature to environmental temperature, due to the capacity of the animal body to store a large amount of heat upon increase in environmental temperature, which is dissipated slowly upon subsequent decrease in environmental temperature. In the present study, it was not uncommon for the experimental-group calves to have higher rectal temperatures after 4 hours at 85°F than they had previously at 95°F air temperature. This lag in rectal temperature response cannot be attributed entirely to the heat capacities of the calves' bodies, however, since feeding during the interim and the natural diurnal body temperature pattern, as reported by Wrenn (138), may also have had an effect. In view of the natural diurnal body temperature pattern, it would have been advantageous to collect rectal temperature data from the control-group calves also at three times during the day, but this was not done because of the large amount of time which would have been required.

On the basis of the respiration rate and rectal temperature responses, there was no indication that the experimental-group calves became acclimatized after prolonged exposure to hot conditions.

E. Blood Composition

The attempt to elucidate some of the physiological adjustments which occur in young calves subjected to hot conditions centered around studies of blood composition in the present experiment. The hot

conditions employed in this study affected the experimental-group calves severely, as judged by the criteria of respiration rate, rectal temperature, growth rate, and feed consumption, and thus, they should have been severe enough to bring about any possible characteristic changes in blood composition in the heat-stressed calves. It is unfortunate that no data were collected on the blood volumes of the animals since blood volume changes might have affected the apparent changes in blood composition. Probably this consideration would have been more serious in short-term studies rather than in long-term studies such as the present one. It is hoped that the assumption of absence of relative blood volume differences in the calves of the two groups will not lead to misinterpretations of the blood composition data.

1. Hematocrit and Hemoglobin Values

The average hematocrit values and hemoglobin levels of the calves in both groups for each of the three experimental periods are given in Table 11 and Appendix Table 11a. The analyses of variance of the hematocrit and hemoglobin data are given in Appendix Tables 23a and 24a, respectively. Plots of the prediction equations showing the age trends in hematocrit values and hemoglobin levels for each group are given in Figures 7 and 8, respectively.

The average hematocrit values found in the control-group and experimental-group calves in experimental periods I, II, and III were 48.4 and 41.8, 40.0 and 33.9, and 37.6 and 31.5%, respectively.

TABLE 11

Average hematocrit values and hemoglobin levels of the calves

	Period I		Period II		Period III	
	hematocrit	hemoglobin	hematocrit	hemoglobin	hematocrit	hemoglobin
	(%)	(g./100 ml.)	(%)	(g./100 ml.)	(%)	(g./100 ml.)
Control group means						
Females	51.1	11.16	42.1	9.17	39.2	8.87
Males	45.0	9.84	37.5	8.23	35.8	8.21
Experimental group means						
Females	45.4	10.17	36.5	7.94	32.1	7.17
Males	37.3	7.44	30.6	6.00	30.6	6.86
Females, mean	48.3	10.66	39.3	8.56	35.3	7.94
Males, mean	41.1	8.64	34.0	7.11	33.4	7.58
Control group mean	48.4	10.57	40.0	8.75	37.6	8.56
Experimental group mean	41.8	8.95	33.9	7.08	31.5	7.05
Over-all mean	45.1	9.76	37.0	7.91	34.5	7.78

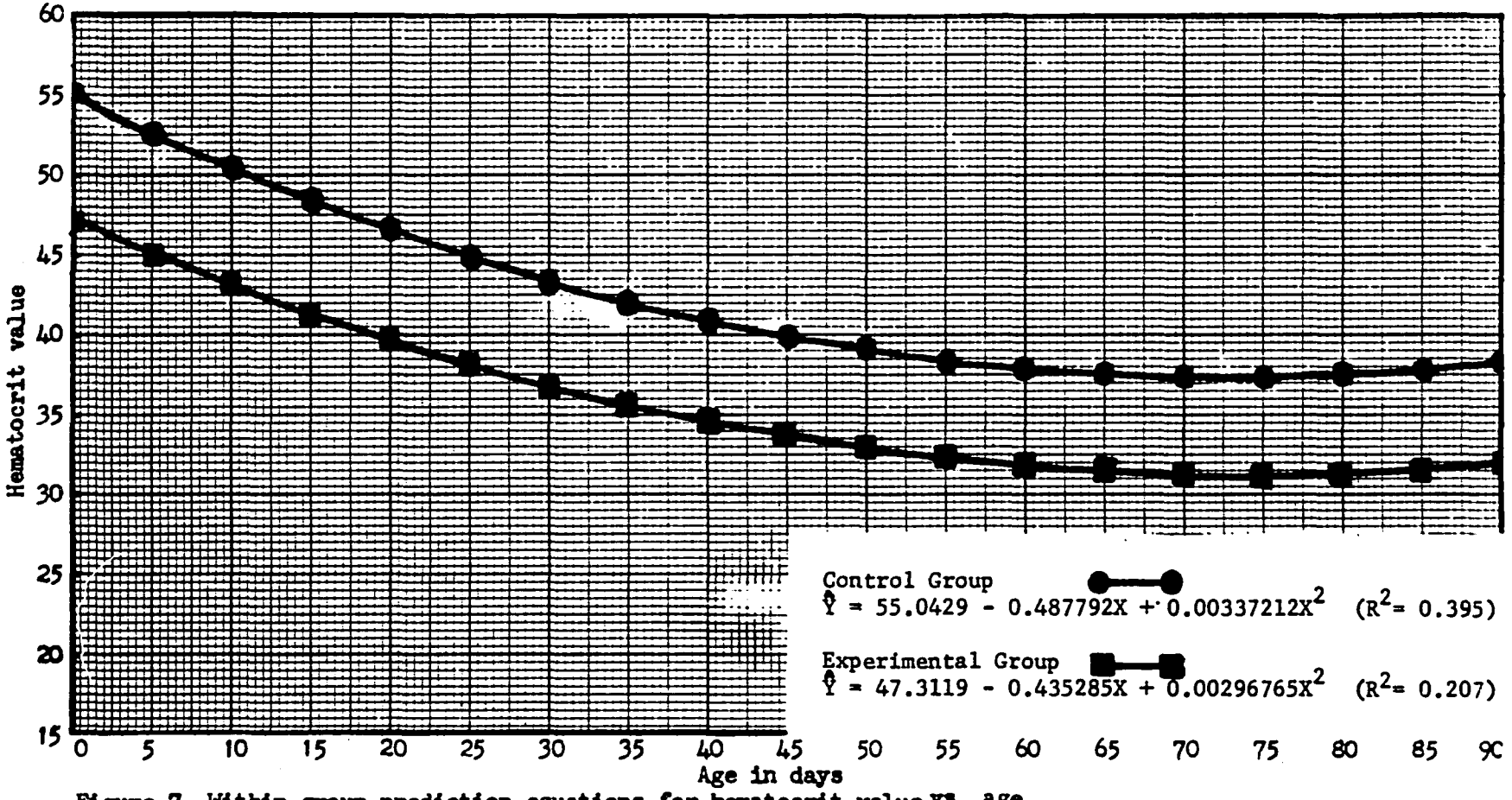

Figure 7. Within-group prediction equations for hematocrit value vs. age

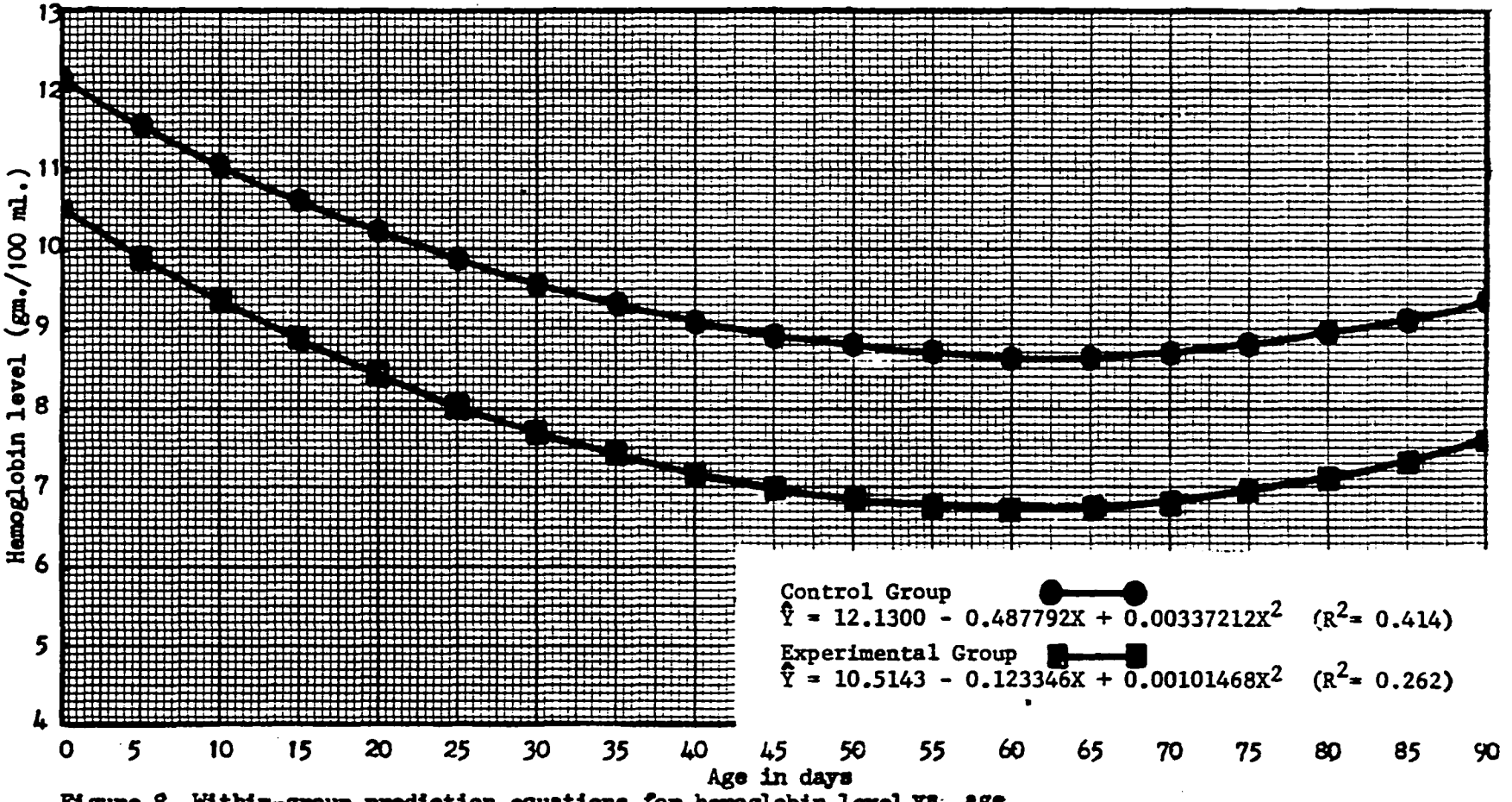

Figure 8. Within-group prediction equations for hemoglobin level vs. age

The between-group differences were nonsignificant in period I, significant ($P < 0.05$) in period II, and highly significant ($P < 0.01$) in period III. The group averages of hematocrit values decreased in the calves of both groups from period I to period II and again from period II to period III. The magnitude of the decreases of the group averages was about the same in the calves of both groups. It was much greater from period I to period II than from period II to period III. Though the group trend was downward, there were several calves in both groups which showed either no change or an increase in average hematocrit value from period II to period III.

The average hemoglobin levels found in the control-group and experimental-group calves in experimental periods I, II, and III were 10.57 and 8.95, 8.75 and 7.08, and 8.56 and 7.05 g. per 100 ml., respectively. The between-group differences were significant ($P < 0.05$) in period I and highly significant ($P < 0.01$) in periods II and III. The group averages of hemoglobin levels behaved similarly to the group average of hematocrit values in showing a large decrease from period I to period II and a small decrease from period II to period III. Several individual calves showed an increase in average hemoglobin level from period II to period III.

The downward trend in hematocrit values and hemoglobin levels which occurred in the calves of both groups for about the first two months of life is most easily seen in Figures 7 and 8. This finding is in agreement with numerous other reports (36, 43, 54, 128, 132, 137). The normal trend with age was accentuated in the experimental-

group calves by exposure to heat since these calves had hematocrit values in periods II and III, and hemoglobin levels in all three periods, which were significantly lower than those of the control-group calves. This result does not agree with the findings of Brody (25), Dale and Brody (30), and Blincoe and Brody (20) that heat exposure produces no consistent change in hematocrit values and hemoglobin levels in Holstein cows. However, the hematocrit and hemoglobin responses to heat stress in young calves may be different from those in mature cattle. The depression in hematocrit values and hemoglobin levels in the heat-stressed calves of the present study may be explained as a negative erythropoetic response to a high oxygen tension in the pulmonary alveoli of these calves. It is very likely that an increased respiratory ventilation rate accompanied the increased breathing rate, and this would result in increased oxygen tension in the alveolar air.

2. Plasma Carotenoid and Vitamin A Values

The average plasma carotenoid and vitamin A levels of the calves in both groups for each of the three experimental periods are given in Table 12 and Appendix Table 12a. The analyses of variance and of covariance of the plasma carotenoid and vitamin A data are given in Appendix Tables 25a through 28a. Plots of the prediction equations showing the age trends in plasma carotenoid and vitamin A levels for each group are given in Figures 9 and 10, respectively. In Figure 9 the X-intercept of the curve for the control group is unreasonably high and must be regarded as an error arising from extrapolation of the curve back to time zero.

TABLE 12

Average blood plasma carotenoid and vitamin A levels of the calves

	Period I		Period II		Period III	
	carot-enoid	vitamin A	carot-enoid	vitamin A	carot-enoid	vitamin A
	(mcg./100 ml.)					
Control group means						
Females	39.8	17.96	90.3	24.64	177.9	25.92
Males	27.7	19.76	75.8	26.14	171.8	25.28
Experimental group means						
Females	26.6	21.95	39.1	23.19	66.5	15.79
Males	24.0	14.95	56.9	22.17	193.9	21.06
Females, mean	33.2	19.95	64.7	23.92	117.1	20.40
Males, mean	25.9	17.35	66.4	24.16	182.2	23.29
Control group mean	34.4	18.76	83.9	25.31	175.0	25.62
Experimental group mean	25.5	18.84	47.0	22.74	117.5	17.90
Over-all mean	29.9	18.80	65.4	24.02	145.5	21.66

The average plasma carotenoid levels in the control-group and experimental-group calves in periods I, II, and III were 34.4 and 25.5, 83.9 and 47.0, and 175.0 and 117.5 mcg. per 100 ml., respectively. The results of the analyses of variance indicated that the between-group differences were significant ($P < 0.05$) in periods I and II, but not quite significant in period III. When covariance adjustment was made for carotenoid intake, the between-group differences became nonsignificant in all three periods, though the difference approached significance in period I. The plasma carotenoid levels were

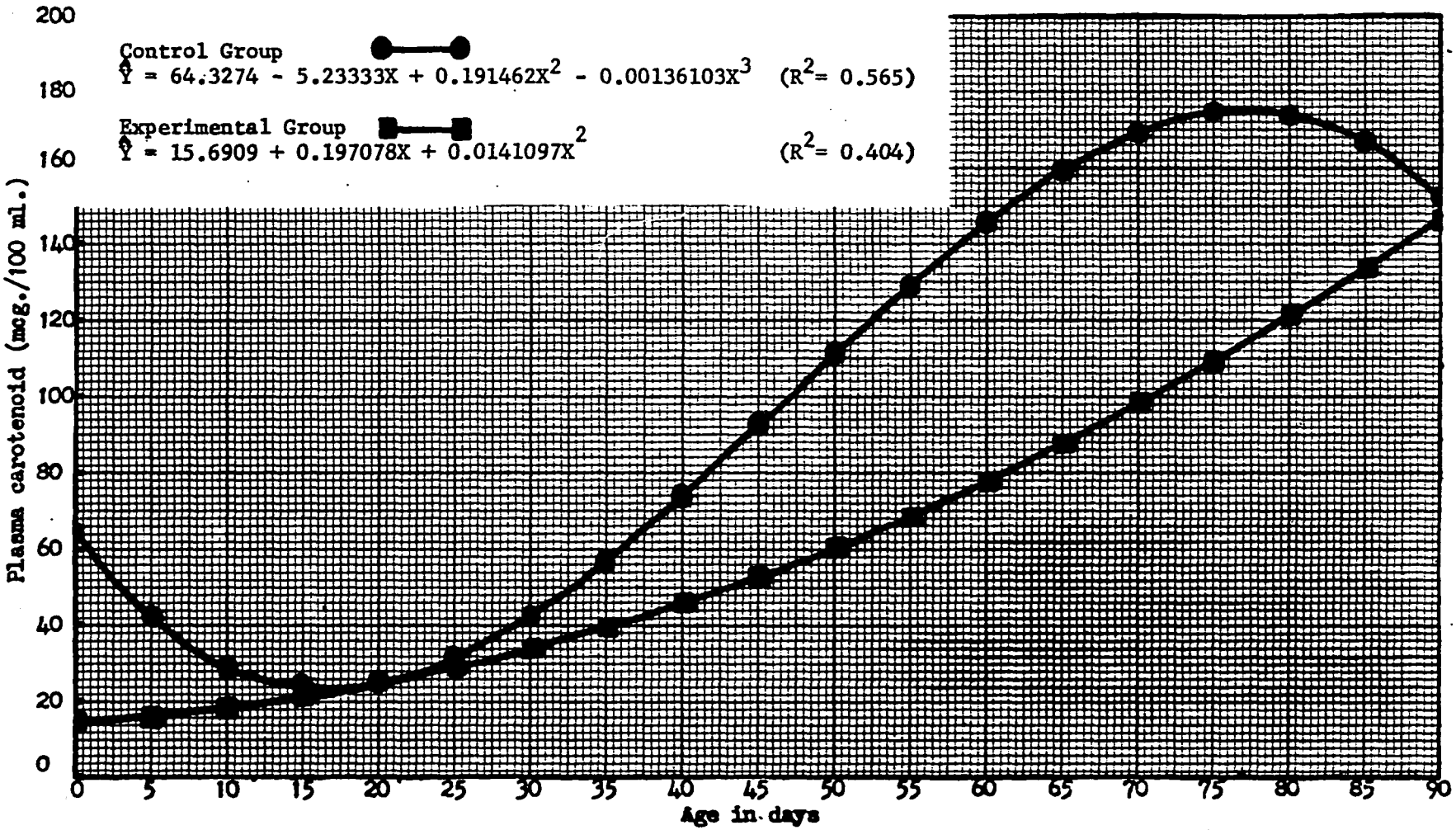

Figure 9. Within-group prediction equations for plasma carotenoid level vs. age

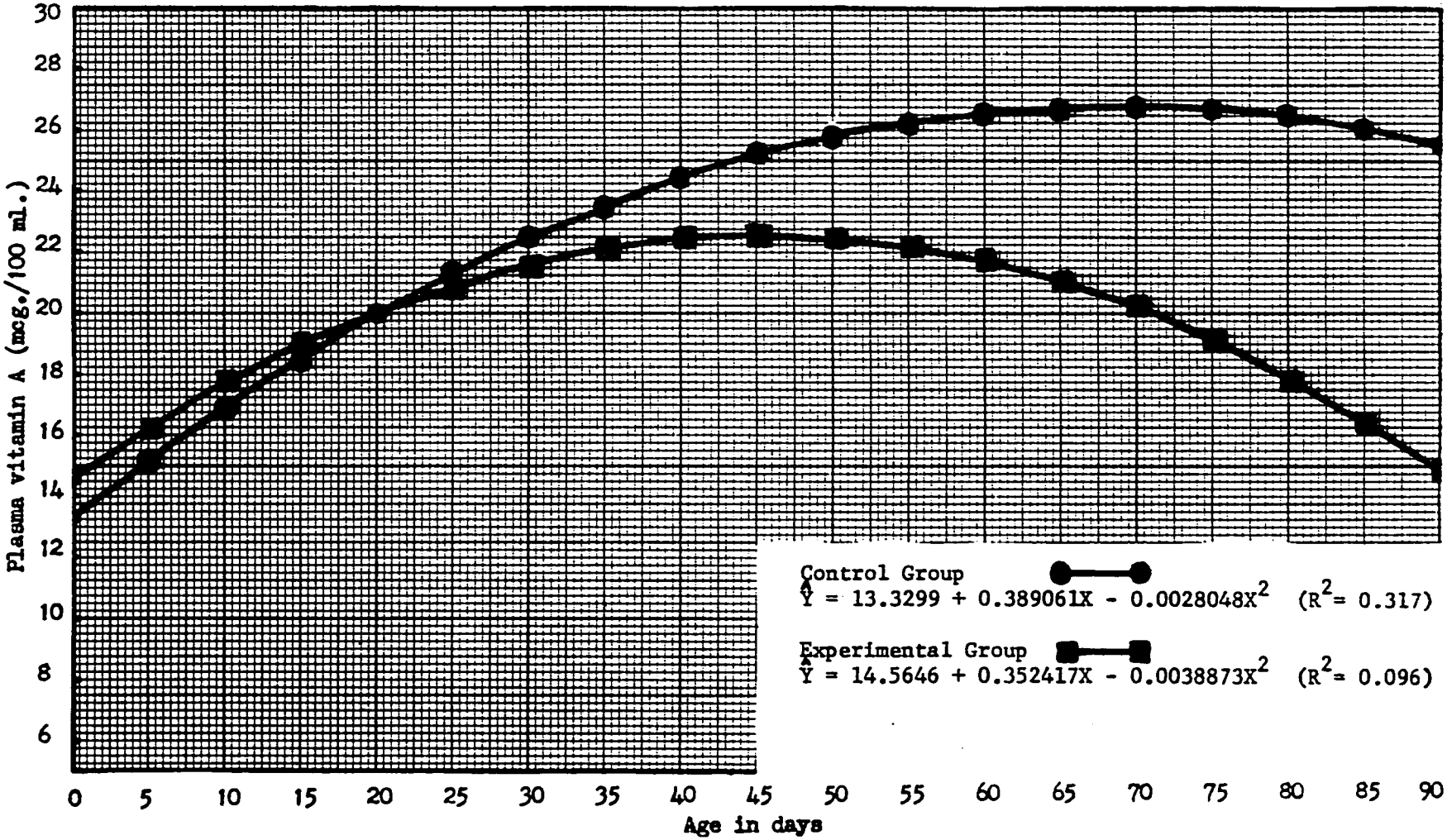

Figure 10. Within-group prediction equations for plasma vitamin A level vs. age

low when blood samples were first taken during the early days of life, i.e., 19.2 and 18.3 mcg. per 100 ml. in the control-group and experimental-group calves, respectively. The levels in the control-group calves rose steadily until about 10 weeks of age, and then decreased slightly, as shown in Figure 9. Wise et al. (136) also observed a continuing increase in blood carotenoid level up to at least 10 weeks of age in calves consuming hay. The levels in the experimental-group calves increased throughout the experimental period. The significantly higher plasma carotenoid levels in the control-group over those of the experimental-group calves in periods I and II were apparently due to greater hay consumption by the calves of the former group because the differences were nonsignificant when covariance adjustment was made for carotenoid intake. The failure of heat stress to produce any direct effect on plasma carotenoid level is in agreement with the results of Stallcup and Herman (124) from a study with cows.

The average plasma vitamin A levels in the control-group and experimental-group calves in periods I, II, and III were 18.76 and 18.84, 25.31 and 22.74, and 25.62 and 17.90 mcg. per 100 ml., respectively. The results of the analyses of variance indicated that the between-group differences were nonsignificant in periods I and II, but highly significant ($P < 0.01$) in period III. When covariance adjustment was made for carotenoid intake, the between-group difference in period III was still significant, but at the $P < 0.05$ level rather than at the $P < 0.01$ level. At first sampling, the plasma of the calves of both groups contained appreciable amounts of vitamin A relative to the normal level in calves, i.e., 16.54 and 18.18 mcg. per 100 ml. in the control-group and experimental-group

calves, respectively. The source of this vitamin A was undoubtedly colostrum, as reported by several workers (93, 105, 125, 136). From inspection of Figure 10, it can be seen that the plasma vitamin A level increased initially in the control-group calves and then leveled off at about 25 mcg. per 100 ml. Wise et al. (136) found a similar leveling off of blood vitamin A at about 15 mcg. per 100 ml. The plasma vitamin A level of the experimental-group calves increased initially up to about 23 mcg. per 100 ml., but then showed a decrease to about 18 mcg. per 100 ml. The significantly higher plasma level of the control-group over the level of the experimental-group calves in period III was probably due primarily to greater grain and hay consumption by the calves of the former group since the F ratio for testing the difference between groups dropped from 13.5 to 5.3 after covariance adjustment was made for carotenoid intake. Thus there was little indication that exposure to hot conditions caused a decrease in the plasma vitamin A levels of young calves under the conditions of this experiment. This finding collaborates the results of Stallcup and Herman (124) and of Page et al. (99) who found no effect of heat stress on plasma vitamin A levels in cattle.

3. Serum Protein Values

The average values for serum total protein level, serum albumin level, and serum albumin/globulin ratio of the calves in both groups for each of the three experimental periods are given in Table 13 and Appendix Table 13a, while those for serum alpha-, beta-, and

TABLE 13

Average levels of serum total protein and albumin and albumin/globulin ratios of the calves

	Period I			Period II			Period III		
	Total protein	Albumin	A/G ratio	Total protein	Albumin	A/G ratio	Total protein	Albumin	A/G ratio
	—(g./100 ml.)—			—(g./100 ml.)—			—(g./100 ml.)—		
Control group means									
Females	6.42	2.01	0.46	6.24	2.17	0.54	6.44	2.35	0.58
Males	6.22	1.99	0.50	5.95	2.14	0.57	6.39	2.44	0.62
Experimental group means									
Females	6.16	1.88	0.46	5.83	2.15	0.59	6.30	2.18	0.53
Males	4.76	1.81	0.62	5.26	2.07	0.66	5.99	2.44	0.69
Females, mean	6.30	1.94	0.46	6.04	2.16	0.56	6.36	2.25	0.55
Males, mean	5.49	1.90	0.56	5.60	2.11	0.62	6.20	2.44	0.66
Control group mean	6.33	2.00	0.48	6.11	2.16	0.55	6.42	2.39	0.60
Experimental group mean	5.54	1.85	0.53	5.58	2.11	0.62	6.17	2.28	0.60
Over-all mean	5.94	1.93	0.50	5.84	2.14	0.59	6.29	2.34	0.60

gamma- globulin levels are given in Table 14 and Appendix Table 14a. The analyses of variance and of covariance of the serum protein data are given in Appendix Tables 29a through 39a. Plots of the prediction equations showing the age trends in serum total protein and serum protein fractions for each group are given in Figures 11 through 15.

a. Total Protein Level. The average serum total protein levels in the control-group and experimental-group calves in periods I, II, and III were 6.33 and 5.54, 6.11 and 5.58, and 6.42 and 6.17 g. per 100 ml., respectively. The results of the analyses of variance indicated that the between-group differences were significant ($P < 0.05$) in periods I and III and highly significant ($P < 0.01$) in period II. However, when covariance adjustment was made for protein intake, none of these differences remained significant. The serum total protein levels in several individual calves showed marked increases or decreases during the early weeks of life. This is reflected in large differences in the average serum total protein levels between period I and period II seen in Appendix Table 13a. Generally, much smaller differences were shown between periods II and III. From inspection of Figure 11, it can be observed that serum total protein levels in the calves of both groups decreased slightly for about the first 30 days of life and then gradually increased again, exceeding their initial levels by 90 days. The reason for the initial decline is not clear. It might be due to the limited ability of the newborn calf to synthesize serum proteins.

TABLE 14

Average levels of serum alpha-, beta-, and gamma-globulins of the calves

	Period I			Period II			Period III		
	Alpha-	Beta-	Gamma-	Alpha-	Beta-	Gamma-	Alpha-	Beta-	Gamma-
	Globulins			globulins			globulins		
	(g./100 ml.)								
Control group means									
Females	1.25	1.60	1.57	1.11	1.50	1.45	1.16	1.49	1.46
Males	1.44	1.43	1.35	1.16	1.41	1.24	1.21	1.35	1.39
Experimental group means									
Females	1.24	1.75	1.30	1.07	1.42	1.20	1.09	1.49	1.55
Males	1.41	1.05	0.48	1.04	1.19	0.96	0.92	1.30	1.33
Females, mean	1.24	1.67	1.43	1.09	1.46	1.32	1.12	1.49	1.51
Males, mean	1.42	1.24	0.92	1.10	1.30	1.10	1.07	1.33	1.36
Control group mean	1.33	1.52	1.47	1.13	1.46	1.36	1.18	1.42	1.43
Experimental group mean	1.32	1.44	0.93	1.06	1.31	1.09	1.02	1.41	1.46
Over-all mean	1.32	1.48	1.20	1.09	1.39	1.22	1.10	1.42	1.44

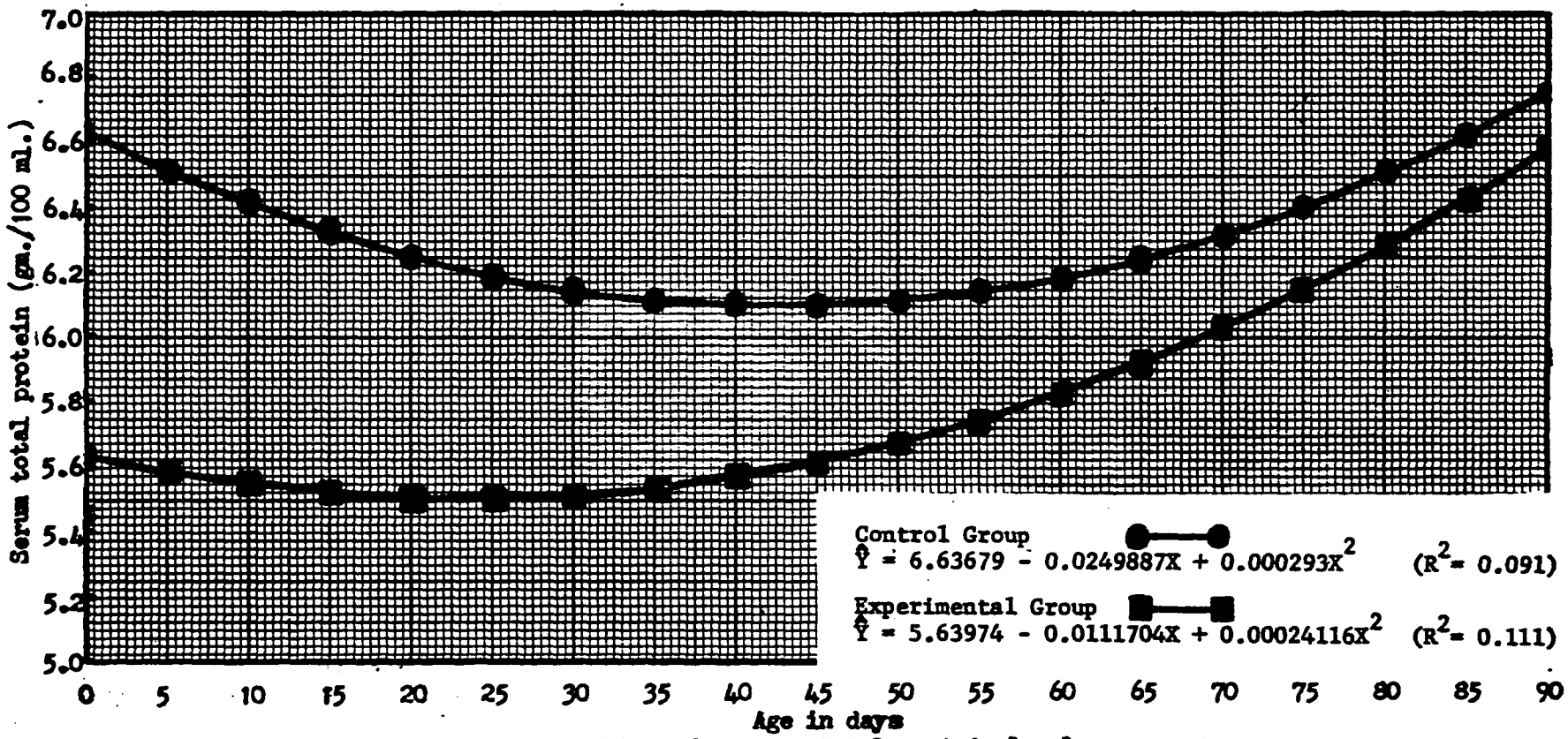

Figure 11. Within-group prediction equations for serum total protein level vs. age

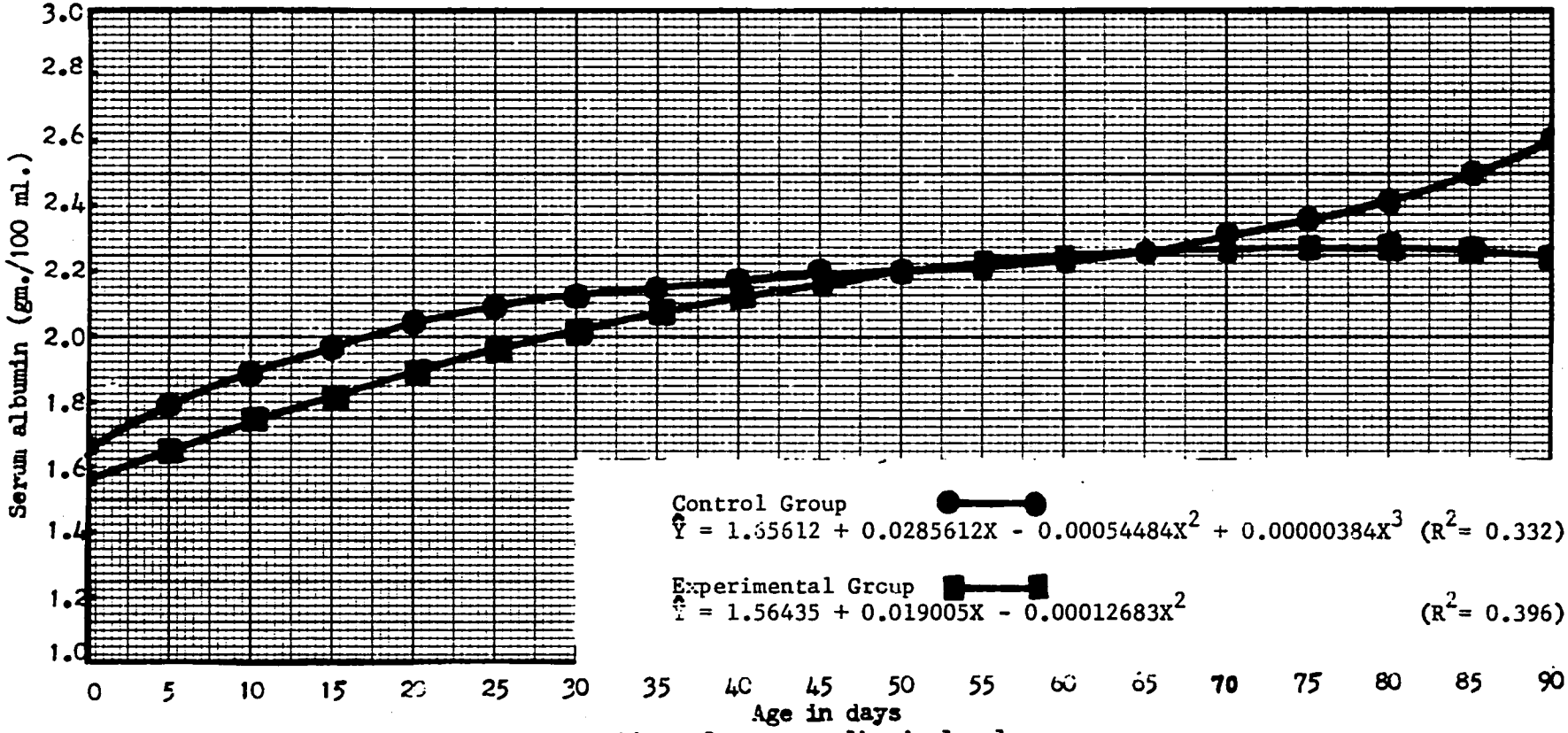

Figure 12. Within-group prediction equations for serum albumin level vs. age

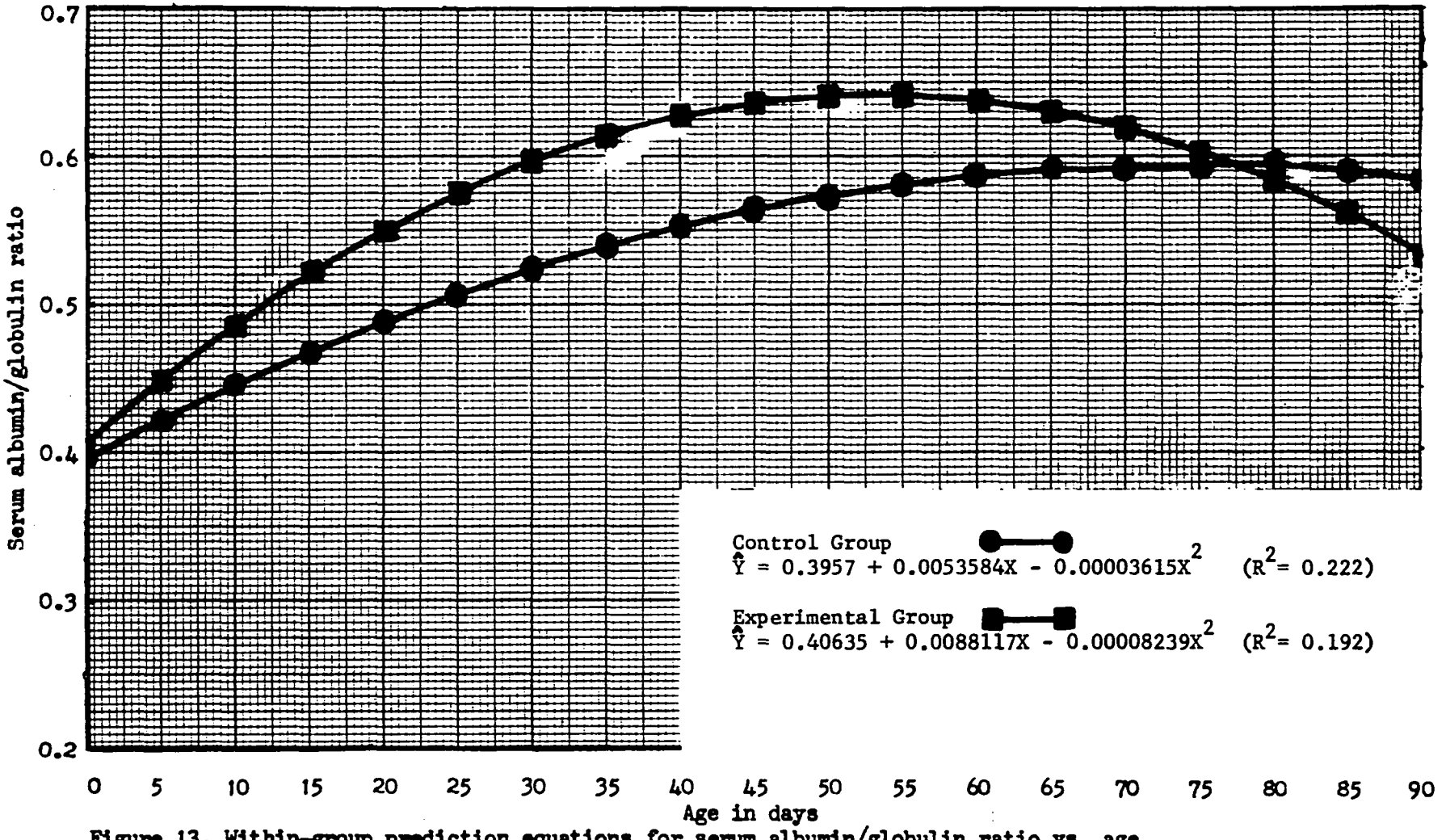

Figure 13. Within-group prediction equations for serum albumin/globulin ratio vs. age

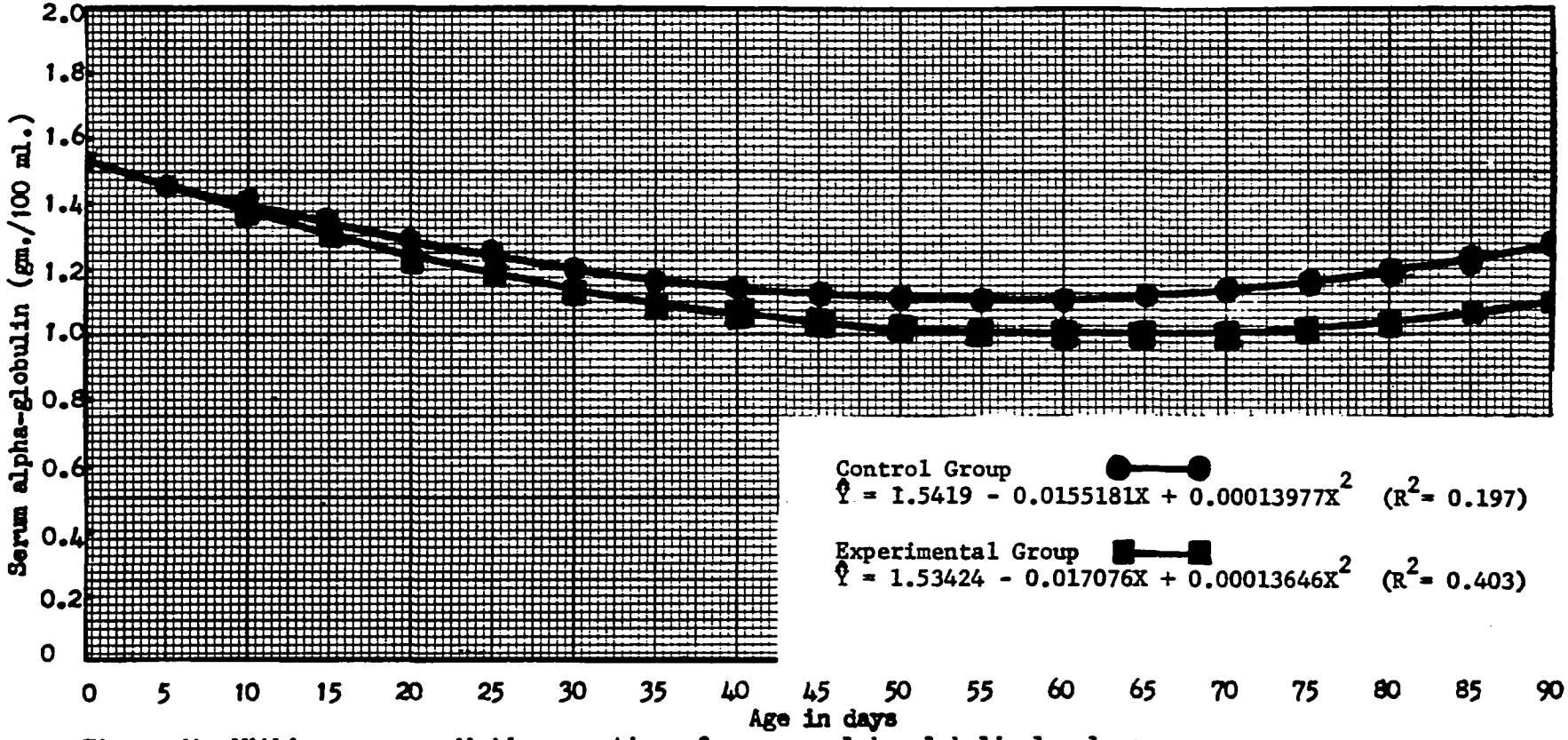

Figure 14. Within-group prediction equations for serum alpha-globulin level vs. age

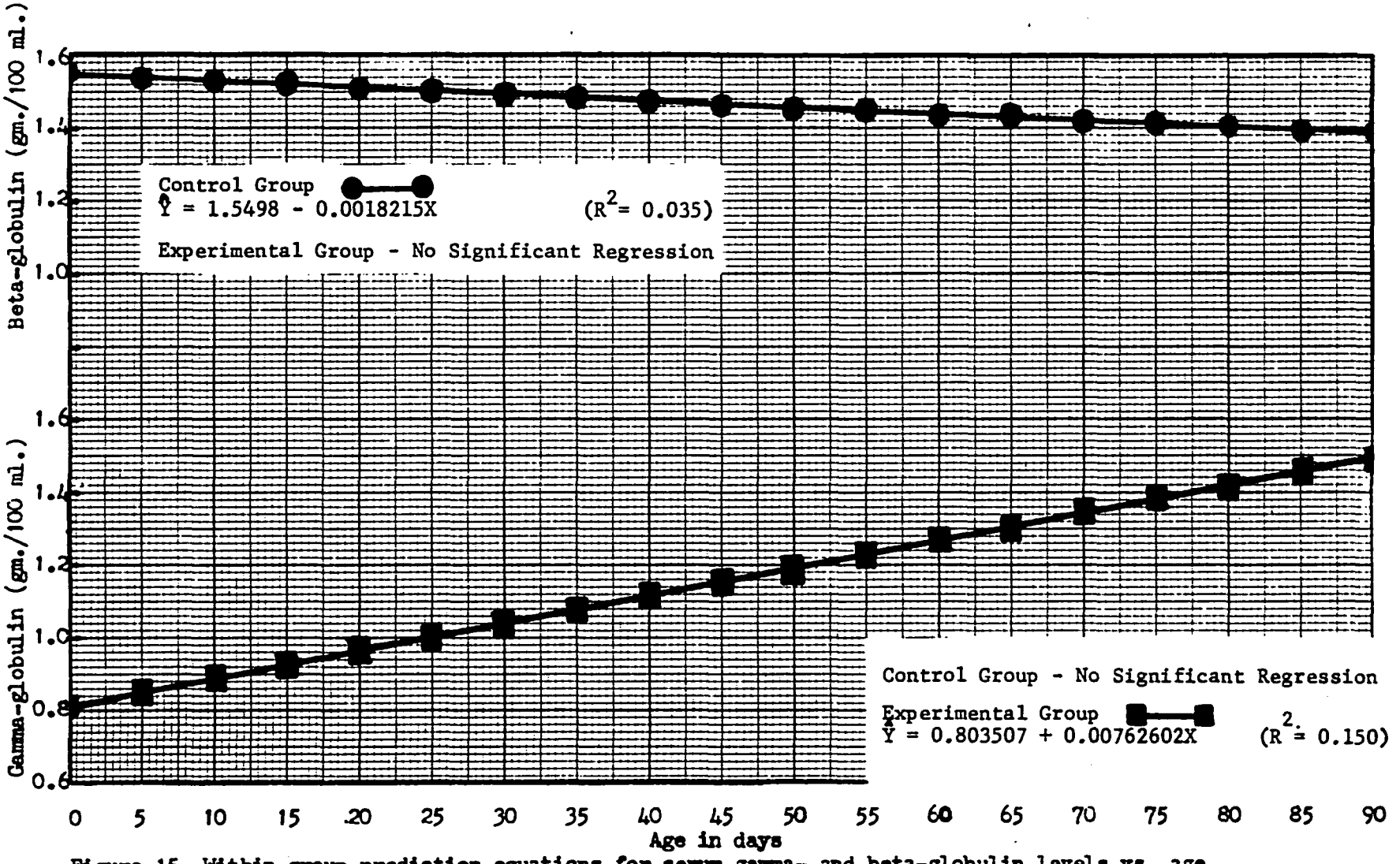

Figure 15. Within-group prediction equations for serum gamma- and beta-globulin levels vs. age

The higher serum total protein levels of the control-group over those of the experimental-group calves in all three periods appears to have been merely a reflection of greater nitrogen consumption by the control-group calves since the differences became nonsignificant when covariance adjustment was made for protein intake. Kamal et al. (67) also found a decline in plasma protein concentration in dairy heifers at high environmental temperatures, and attributed the decline to decreased nitrogen intake and possibly increased plasma volume. Other experiments with mature cattle have not revealed any effect of heat stress upon plasma total protein concentration (20, 25, 30).

b. Albumin Level. The average serum albumin levels in the control-group and experimental-group calves in periods I, II, and III were 2.00 and 1.85, 2.16 and 2.11, and 2.39 and 2.28 g. per 100 ml., respectively. The between-group differences were nonsignificant in all three periods, either with or without covariance adjustment for serum total protein level. The serum albumin levels of the control-group calves increased steadily with age, as shown in Figure 12. This finding is in accord with the usual trend as reported by other workers (48, 81, 133). The serum albumin levels of the experimental-group calves increased initially and then tended to level off after about 50 days of age. Near the end of the experimental period the serum albumin level of the control-group calves was apparently becoming higher than the level of the experimental-group calves; thus, heat exposure prolonged beyond

two months might have had the effect of decreasing the level of this serum protein fraction.

c. Albumin/Globulin Ratio. The average serum albumin/globulin ratios in the control-group and experimental-group calves in periods I, II, and III were 0.48 and 0.53, 0.55 and 0.62, and 0.60 and 0.60, respectively. The between-group differences were nonsignificant in all three periods. Inspection of Figure 13 reveals that the serum albumin/globulin ratio of the control-group calves increased from about 0.42 at 5 days of age to 0.59 at 75 days of age and then decreased very slightly, while the ratio of the experimental-group calves increased from 0.45 at 5 days to 0.64 at 55 days and then showed a sharp decrease down to 0.53 at 90 days. Near the end of the experimental period the difference between groups in albumin/globulin ratio was becoming larger in favor of the control-group calves. It is interesting to speculate what the effect on the results with respect to albumin/globulin ratio would have been if the data for period III had been complete and/or if the experimental period had been continued beyond 90 days of age since the present results give only a slight indication that heat exposure beyond two months decreased the serum albumin/globulin ratio.

d. Alpha-Globulin Level. The average serum alpha-globulin levels in the control-group and experimental-group calves in periods I, II, and III were 1.33 and 1.32, 1.13 and 1.06, and 1.18 and 1.02 g. per 100 ml., respectively. The results of the analyses of variance indicated that the between-group differences were nonsignificant

in periods I and II, but highly significant ($P < 0.01$) in period III. When covariance adjustment was made for serum total protein level, the between-group differences were significant ($P < 0.05$) in period I, highly significant ($P < 0.01$) in period III, and approached significance in period II. Surprisingly, the serum alpha-globulin level was negatively correlated with serum total protein level in period I, therefore, the significant between-group difference of the adjusted values was in favor of the control-group calves in this period. Serum alpha-globulin level was positively correlated with serum total protein level in periods II and III, which is a more logical relationship than that found in period I. The serum alpha-globulin levels in the calves of both groups decreased during the early weeks of life, then they tended to level off, and finally increased slightly toward the end of the experimental period, as shown in Figure 14. The finding of an initial decrease in serum alpha-globulin is in agreement with numerous other reports (48, 56, 81, 107, 122, 131). Since the alpha-globulin level of the control-group calves was significantly higher than that of the experimental-group calves in period III, both on an absolute basis and after covariance adjustment to eliminate the effect of differences in serum total protein, there was an indication that prolonged heat exposure caused a reduction in the serum alpha-globulins of young calves under the conditions of this study.

e. Beta-Globulin Level. The average serum beta-globulin levels in the control-group and experimental-group calves in periods I,

II, and III were 1.52 and 1.44, 1.46 and 1.31, and 1.42 and 1.41 g. per 100 ml., respectively. The results of the analyses of variance indicated that the between-group difference was significant ($P < 0.05$) only in period II. When covariance adjustment was made for serum total protein level, the between-group difference was highly significant ($P < 0.01$) in period I, but nonsignificant in the other two periods. From Figure 15, it can be seen that the serum beta-globulin level of the control-group calves showed a slight and erratic ($R^2 = 0.035$) downward trend throughout the experimental period. There was no significant regression of serum beta-globulin level on age in the experimental-group calves. Varnell et al. (131) also noted only slow changes in the beta-globulins with age, though the trend was up instead of down in their calves. In the present study, it did not appear that heat stress had any consistent effect upon the serum beta-globulin fraction. The average serum beta-globulin levels of the female calves were significantly higher than those of the male calves in all three periods in analysis of variance. This was the only Y variable studied which consistently showed a significant between-sex difference. It might be noted that none of the Y variables consistently showed a significant group x sex interaction.

f. Gamma-Globulin Level. The average serum gamma-globulin levels in the control-group and experimental-group calves in periods I, II, and III were 1.47 and 0.93, 1.36 and 1.09, and 1.43 and 1.46 g. per 100 ml., respectively. The results of the analyses of variance indicated that the between-group differences were significant

($P < 0.05$) in period I, highly significant ($P < 0.01$) in period II, and nonsignificant in period III. When covariance adjustment was made for serum total protein level, the between-group differences were nonsignificant in all three periods. As can be seen from Figure 15, the serum gamma-globulin level of the experimental-group calves increased throughout the experimental period. There was no significant regression of serum gamma-globulin level on age in the control-group calves. The trend in neither group was in agreement with that of a steady decrease with age, as reported by Varnell et al. (131). However, the initial proportion of gamma-globulin relative to the other serum protein fractions was less in the calves of the present study than in the calves studied by Varnell et al. The control-group calves had initially higher levels of serum gamma-globulin and they maintained this initial advantage in periods I and II but not in period III. The final gamma-globulin levels were higher in the experimental-group than in the control-group calves, and the level was still rising in the former group at the end of the experimental period so that there appeared to be an increase in the serum gamma-globulin levels of young calves due to prolonged heat exposure under the conditions of this study.

F. General Discussion

The present study is a contribution to the limited knowledge of the effect of heat stress upon Holstein calves from birth through the first few months of life. It is assumed that dairy calves of other temperature breeds would respond in a reasonably similar

manner though perhaps they would not be quite as severely affected since Johnson and Ragsdale (57) found that Holstein calves were more heat sensitive than either Jersey or Brown Swiss calves.

Although this experiment was necessarily limited to a rather small sample size, the statistically significant results, with respect to the effect of heat stress upon feed consumption and growth, reflect responses which were so obvious that reliance can be placed in the conclusions which have been drawn regarding these criteria. The effect of heat exposure and its carry-over effect can be comprehended most easily by considering the mean body weights of the control-group and experimental-group calves at birth, 90 days (end of experimental period) and 150 days (end of post-experimental period). These figures were 84 and 80, 189 and 140, and 302 and 217 lb., respectively. Though the mean birth weights of the calves of both groups were nearly the same, the mean body weight of the heat-stressed calves lagged behind that of the non-stressed calves by 40 lb. after 90 days of heat exposure, and by 85 lb. after 90 days of heat exposure followed by 60 days under comfortable climatic conditions. The differences in mean body weight between groups might have been still greater if four of the calves in the experimental group had not been removed from the hot environment before they had completed the full 90 days of the experimental period.

One of the limiting factors of the growth rates of the experimental-group calves was definitely feed consumption. Another factor which may have been limiting, and which was not taken into account in this experiment was total water consumption. The calves

of both groups received practically the same total water allowances, either as whole milk, skim milk, or free water, in accord with the standard calf-feeding practices employed with the L.S.U. dairy herd. However, it is likely that the experimental-group calves had higher water requirements, since they must have been vaporizing more moisture than the control-group calves. If the experimental-group calves were receiving less than an optimal amount of total water this may have limited their feed intake, since solid feed must be mixed with water in the gut. One possibility for further research in this area is to study the effect of providing heat-stressed calves with greater than usual total water allowances.

It can only be speculated as to what the effect of continued exposure to the hot conditions employed in this study beyond 90 days of age would have been. It is not unlikely that two or more of the experimental-group calves would not have survived or at least would have been permanently stunted by more prolonged exposure. These results indicate the difficulty of raising Holstein calves in a subtropical environment. Indeed, the inability of calves of the Holstein and other temperate breeds to develop normally in subtropical areas have been observed repeatedly. However, a concerted effort on the part of the nutritionist, the physiologist, and the geneticist might eventually lead to a strain of Holstein calves and a system of calf raising which would enable normal development of calves of this breed under subtropical conditions.

Though the results of this study are conclusive in demonstrating the effect of heat stress upon feed consumption and growth

in young Holstein calves, they are not conclusive in demonstrating the effect of heat stress upon digestibility or blood composition. The magnitude of and the consistency of the between-group differences observed in the latter criteria were less than those observed in the former criteria. Consideration of this and the fact that the sample size was limited in this study, makes it obvious that more extensive research is needed to confirm or disprove the tentative conclusions as to the effect of heat stress upon digestibility and blood composition which have been reached in the present study. In addition to apparent digestibility, such criteria as true digestibility, nitrogen balance, mineral balances, metabolizable energy, and net energy might profitably be investigated to determine the effect of heat stress upon the over-all picture of nutrient utilization in the young calf.

Further research on the effect of heat stress on blood composition might profitably include studies on such constituents as glucose, nonprotein nitrogenous substances, electrolytes, enzymes and hormones. Of the latter group the adrenocorticoids might be of special interest, since they are concerned in the response of the animal to stress, and since they interact with the somatotrophic hormone in regulating nitrogen balance.

SUMMARY

An experiment was conducted involving two groups of Holstein calves, consisting of five females and four males each. One of the groups was housed in individual stalls in the L.S.U. physhrometric chamber and the other group in an open-air barn. The calves were placed on the experiment at 4 days of age and taken off at 90 days of age when possible. The experiment was terminated when the final four calves in each group were between the ages of 60 and 90 days, since the psychrometric chamber no longer was available for use in this experiment.

The group in the psychrometric chamber was subjected to air temperatures cycling diurnally from 75° to 95°F, with 10 hr. at 75°F, 8 hr. at 85°F, and 6 hr. at 95°F. The vapor pressure was held constant at 20 mm. Hg. The group in the calf barn was subjected to ambient winter temperature and vapor pressure conditions, though protected from wind and precipitation.

The feeding and management regimen was kept as similar as possible for both groups. The calves received whole milk until 3 wk. of age, then skim milk until 8 wk. of age. They were fed a calf grain mixture and excellent quality alfalfa hay ad libitum.

The calves were weighed once a week. Respiration rate and rectal temperature determinations were also made during one day each

week. These were made once during the day on the control-group calves, and three times during the day, once at each specific air temperature in the chamber, on the experimental-group calves.

Blood samples were collected by jugular puncture from the calves at 5-day intervals until 60 days of age, then at 10-day intervals until 90 days of age.

At some time between the ages of 60 and 90 days, the calves were subjected to individual digestibility trials employing the chromic oxide indicator method. Digestibility coefficients were determined for dry matter, drude protein, total nutrients and energy.

The experiment was analyzed as three separate periods, viz., period I, from birth to 30 days of age; period II, from 31 to 60 days of age; and period III, from 61 to 90 days of age.

Between the ages of 91 and 150 days the calves were maintained in groups in outside pens. This period was designated the post-experimental period. Weekly weighings were continued during this period.

The average daily body weight gains of the control-group and experimental-group calves in experimental periods I, II, and III, and the post-experimental period were 0.74 and 0.56, 1.19 and 0.74, 1.50 and 0.56, and 0.94 and 0.65 lb., respectively. The between-group difference was nonsignfficant in period I, but highly significant ($P < 0.01$) in all the other periods. Thus, the average growth rate of the calves under hot conditions was lower than that of the calves under cool conditions throughout the experiment, especially from 31

to 90 days of age, and even in the post-experimental period when the calves of both groups were subjected to the same environment.

The average daily grain dry matter intakes of the control-group and experimental-group calves in experimental periods I, II, and III were 0.48 and 0.19, 1.30 and 0.43, and 3.36 and 1.70 lb., respectively. The between-group difference was significant ($P < 0.05$) in period I and highly significant ($P < 0.01$) in periods II and III. The corresponding figures for hay dry matter intake were 0.07 and 0.03, 0.54 and 0.24, and 1.18 and 0.73 lb., respectively. The between-group difference was significant ($P < 0.05$) only in period II. Thus, the calves under hot conditions consumed smaller amounts of grain and hay than did the calves under cool conditions.

The mean digestibility coefficients determined in seven calves each of the control group and experimental group were 69.43 and 66.13 for dry matter, 72.08 and 68.67 for crude protein, 70.43 and 66.60 for total nutrients, and 67.43 and 63.04 for energy, respectively. Thus, the calves under hot conditions showed slightly lower digestive efficiency than did the calves under cool conditions, though the between-group differences were not statistically significant.

The average respiration rates per minute of the control-group calves in periods I, II, and III were 34.3, 43.8, and 53.0, respectively. The average respiration rates per minute of the experimental-group calves at air temperatures 95°, 85°, and 75°F were 93.4, 75.9, and 44.0, respectively, in period I, 100.8, 86.9, and 62.2 in period II, and 96.7, 85.0, and 65.1 in period III. The between-group

differences were all highly significant ($P < 0.01$) except for the difference between the average respiration rate of the control-group calves and the average respiration rate of the experimental-group calves at 75°F in period III which was nonsignificant. Thus, the calves under hot conditions showed markedly higher breathing rates than the calves under cool conditions.

The average rectal temperatures of the control-group calves in periods I, II and III were 102.8°, 103.0°, and 103.1°F, respectively. The average rectal temperatures of the experimental-group calves at air temperatures 95°, 85°, and 75°F were respectively 104.6°, 104.3°, and 103.7°F in period I, 104.9°, 104.9°, and 103.8°F in period II, and 105.3°, 105.2°, and 104.2°F in period III. The between-group differences were highly significant ($P < 0.01$) in all three periods and at all three air temperatures for the experimental group. Thus, the calves under hot conditions were unable to maintain normal body temperature and actually were suffering from heat stress.

The average hematocrit values found in the control-group and experimental-group calves in periods I, II, and III were 48.4 and 41.8, 40.0 and 33.9, and 37.6 and 31.5%, respectively. The between-group difference was nonsignificant in period I, significant ($P < 0.05$) in period II, and highly significant ($P < 0.01$) in period III. The average hemoglobin levels found in the control-group and experimental-group calves in periods I, II, and III were 10.57 and 8.95, 8.75 and 7.08, and 8.56 and 7.05 g. per 100 ml., respectively.

The between-group difference was significant ($P < 0.05$) in period I and highly significant ($P < 0.01$) in periods II and III. Thus, the calves under hot conditions showed lower hematocrit values and hemoglobin levels than the calves under cool conditions.

The average blood plasma carotenoid levels found in the control-group and experimental-group calves in periods I, II, and III were 34.4 and 25.5, 83.9 and 47.0, and 175.0 and 117.5 mcg. per 100 ml., respectively. In analysis of variance, the between-group difference was significant ($P < 0.05$) in periods I and II, but not in period III. With covariance adjustment for carotenoid intake the between-group difference was non-significant in all three periods. The lower plasma carotenoid levels of the calves under hot conditions were apparently due to lesser carotenoid intake by these animals and not to the effect of heat exposure per se.

The average blood plasma vitamin A levels found in the control-group and experimental-group calves in periods I, II, and III were 18.76 and 18.84, 25.31 and 22.74, and 25.62 and 17.90 mcg. per 100 ml., respectively. In analysis of variance the between-group difference was nonsignificant in periods I and II, but highly significant ($P < 0.01$) in period III. With covariance adjustment for carotenoid intake the between-group difference was significant ($P < 0.05$) in period III only. The higher average plasma vitamin A level in the control-group calves than in the experimental-group calves in period III appeared to be due primarily to greater hay and grain consumption by calves of the former group, thus there

was little reason to believe that heat exposure produced a lowering of the plasma vitamin A levels of the experimental-group calves.

The average serum total protein levels found in the control-group and experimental-group calves in periods I, II, and III were 6.33 and 5.54, 6.11 and 5.58, and 6.42 and 6.17 g. per 100 ml., respectively. In analysis of variance the between-group difference was significant ($P < 0.05$) in periods I and III and highly significant ($P < 0.01$) in period II With covariance adjustment for protein intake the between-group difference was nonsignificant in all three periods. The lower serum total protein levels of the calves under hot conditions were apparently due to lesser nitrogen intake by these animals and not to a direct effect of heat exposure.

The average serum albumin levels found in the control-group and experimental-group calves in periods I, II and III were 2.00 and 1.85, 2.16 and 2.11, and 2.39 and 2.28 g. per 100 ml., respectively. The between-group difference was nonsignificant in all three periods both in analysis of variance and with covariance adjustment for serum total protein level. The corresponding figures for serum albumin/globulin ratio were 0.48 and 0.53, 0.55 and 0.62, and 0.60 and 0.60, respectively. The between-group difference was nonsignificant in all three periods. Though there were no statistically significant between-group differences in these two variables, it appeared that the serum albumin levels and serum albumin/globulin ratios of the control-group calves were becoming progressively

greater than those of the experimental-group calves toward the end of period III. Thus, there was a slight indication that prolonged heat exposure depressed the albumin levels and the albumin/globulin ratios of the experimental-group calves.

The average serum alpha-globulin levels found in the control-group and experimental-group calves in periods I, II, and III were 1.33 and 1.32, 1.13 and 1.06, and 1.18 and 1.02 g. per 100 ml., respectively. In analysis of variance the between-group difference was nonsignificant in periods I and II, but highly significant ($P < 0.01$) in period III. With covariance adjustment for serum total protein level the between-group difference was significant ($P < 0.05$) in period I and highly significant ($P < 0.01$) in period III. The higher average serum alpha-globulin level in the control-group than in the experimental-group calves in period III appeared to be a direct effect of the treatment; thus, there was an indication that prolonged heat exposure depressed the levels of this serum protein fraction in the experimental-group calves.

The average serum beta-globulin levels found in the control-group and experimental-group calves in periods I, II, and III were 1.52 and 1.44, 1.46 and 1.31, and 1.42 and 1.41 g. per 100 ml., respectively. In the analysis of variance the between-group difference was significant ($P < 0.05$) only in period II. With covariance adjustment for serum total protein level the between-group difference was highly significant ($P < 0.01$) only in period I. There did not appear to be any consistent effect of heat exposure on this serum protein fraction.

The average serum gamma-globulin levels found in the control-group and experimental-group calves in periods I, II, and III were 1.47 and 0.93, 1.36 and 1.09, and 1.43 and 1.46 g. per 100 ml., respectively. In the analysis of variance the between-group difference was significant ($P < 0.05$) in period I and highly significant ($P < 0.01$) in period II. With covariance adjustment for serum total protein level the between-group difference was nonsignificant in all three periods. Though the experimental-group calves never did show significantly higher levels of this serum protein fraction than the control-group calves, they did show a consistent rise in the average level throughout the experiment, which the control-group did not, and toward the end of period III their average level appeared to be becoming progressively greater than that of the control-group calves. Thus, there was some slight evidence that prolonged heat exposure elevated the serum gamma-globulin levels of the experimental-group calves.

The conclusions drawn from the results of this experiment on blood composition changes in young calves due to heat stress are only tentative because of the limited extent of the data (especially in period III), the lack of statistically significant results in the case of several blood constituents, and the possible confounding effect of changes in relative blood volume between the two groups. The conclusion drawn with respect to the effect of heat stress on digestibility is also only tentative because of the small sample size and the lack of statistically significant results. Far

more reliance can be placed in the conclusions which have been drawn from this experiment regarding the effects of heat stress on growth rate and feed intake in young calves.

CONCLUSIONS

The results of this experiment are rather conclusive in demonstrating that climatic conditions of diurnally cycling 75° to 95°F air temperatures accompanied by 20 mm. Hg. vapor pressure (reasonably simulating typical Louisiana summertime conditions) represent a stressful environment for Holstein calves from birth to 3 mo. of age. Under these conditions young Holstein calves show markedly increased respiratory activity, yet they are unable to maintain normal body temperature. Their consumption of grain and hay is greatly reduced and their digestive efficiency may also be reduced slightly. As a result, their growth rate is drastically reduced, and the retardation of growth is not quickly overcome when the thermal stress is removed. These effects are not manifest equally in all calves, since some calves are more severely influenced by heat exposure than others.

It appears that one of the specific physiological responses of young Holstein calves when subjected to heat stress is a decrease in blood hematocrit values and hemoglobin levels. There does not appear to be any effect of heat stress upon plasma carotenoid or vitamin A levels, except as the carotenoid intake of the calves is affected. Serum total protein levels tend to be reduced in young, heat-stressed calves, but this appears to be due to

lowered nitrogen intake by the calves. Of the individual serum protein fractions, albumin and alpha-globulin levels may decrease, gamma-globulin levels may increase, and the albumin/globulin ratio may decline due to the effects of prolonged heat stress.

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APPENDIX

TABLE 1a

Chemical analyses of composite feces samples collected during the digestion trials (dry matter basis)

Animal	Dry matter	Crude protein	Ether extract	Crude fiber	Nitrogen free extract	Ash	Gross energy	Chromic oxide
	%						cal./g.	mg./g.
Control Group								
631	24.3	19.5	3.4	27.2	37.7	12.2	4,611	6.6
633	22.8	20.9	4.4	20.8	39.0	14.9	4,364	7.4
531-1	24.2	21.9	7.7	20.7	28.3	21.4	4,661	10.7
636	28.8	20.4	2.3	24.2	45.8	7.3	4,712	4.2
501-1	27.0	22.2	2.6	25.5	42.6	7.1	4,750	4.4
296-4	24.2	20.6	4.4	25.1	43.1	6.8	4,732	4.9
638	20.4	22.1	3.0	24.7	42.4	7.8	4,715	7.1
Mean	24.5	21.1	4.0	24.0	39.8	11.1	4,649	6.5
Experimental Group								
632	27.3	18.3	4.5	23.2	43.7	10.3	4,611	8.0
438-1	20.8	20.0	3.9	23.5	38.6	14.0	4,554	10.2
634	23.1	20.5	4.6	20.5	37.5	16.9	4,682	13.2
635	20.6	20.8	2.8	29.9	36.5	10.0	4,680	9.0
637	24.4	28.1	5.3	19.6	38.1	8.9	5,092	11.7
446-1	19.0	21.3	3.2	28.8	36.1	10.6	4,686	11.8
75-3	22.2	23.2	3.2	26.8	39.2	7.6	4,747	7.9
Mean	22.5	21.7	3.9	24.6	38.5	11.2	4,722	10.3
Over-all mean	23.5	21.4	4.0	24.3	39.2	11.1	4,686	8.4

TABLE 2a

Chemical analyses of the composite samples of grain fed during the digestion trials (dry matter basis)

Animal	Dry matter	Crude protein	Ether extract	Crude fiber	Nitrogen free extract	Ash	Gross energy
			%				cal./g.
Control Group							
631	87.8	21.2	2.8	6.7	61.0	8.3	4,277
633	87.8	21.2	2.8	6.7	61.0	8.3	4,277
531-1	87.7	21.8	2.4	8.0	62.3	5.5	4,372
636	87.8	21.1	2.7	8.3	63.2	4.7	4,410
510-1	88.0	20.8	2.7	9.2	62.2	5.1	4,442
296-4	88.3	19.7	4.0	8.8	61.5	6.0	4,418
638	88.3	21.6	3.7	8.6	59.9	6.2	4,403
Mean	88.0	21.1	3.0	8.0	61.6	6.3	4,371
Experimental Group							
632	87.4	23.8	3.0	7.3	55.1	10.8	4,251
438-1	87.4	23.8	3.0	7.3	55.1	10.8	4,251
634	87.9	24.9	2.2	6.6	52.1	14.2	4,096
635	87.8	22.6	3.1	8.8	58.2	7.3	4,360
637	87.8	20.6	3.1	9.1	61.7	5.5	4,330
446-1	87.8	19.9	2.7	9.0	62.9	5.5	4,396
75-3	88.1	21.9	2.6	9.2	59.8	6.5	4,445
Mean	87.7	22.5	2.8	8.2	57.8	8.7	4,304
Over-all Mean	87.8	21.8	2.9	8.1	59.7	7.5	4,338

TABLE 3a

Chemical analyses of the composite samples of grain refused during the digestion trials (dry matter basis)

Animal	Dry matter	Crude protein	Ether extract	Crude fiber	Nitrogen free extract	Ash	Gross energy
	%						cal./g.
Control Group							
631	87.0	34.4	2.6	6.0	39.1	17.9	4,027
633	87.5	28.6	2.9	6.5	49.0	13.0	4,170
531-1	88.1	26.2	1.7	7.6	55.6	8.9	4,389
636	88.1	25.4	3.3	8.9	57.1	5.3	4,443
510-1	87.1	28.0	2.4	7.9	53.9	7.8	4,415
296-4	87.3	26.7	2.8	8.7	54.5	7.3	4,488
638	87.3	32.2	3.8	8.2	47.9	7.9	4,465
Mean	87.5	28.8	2.8	7.7	51.0	9.7	4,342
Experimental Group							
632	86.4	33.9	2.3	5.8	40.6	17.4	4,036
438-1	86.7	26.3	2.1	6.8	54.1	10.7	4,160
634	88.4	24.2	1.9	6.4	53.4	14.1	4,014
635	86.6	32.1	2.2	7.6	46.2	11.9	4,255
637	87.3	23.0	2.3	9.5	59.4	5.8	4,310
446-1	86.0	31.9	3.0	9.5	47.7	7.9	4,449
75-3	87.8	28.5	5.1	9.3	49.6	7.5	4,491
Mean	87.0	28.6	2.7	7.8	50.1	10.8	4,245
Over-all Mean	87.3	28.7	2.7	7.8	50.6	10.2	4,294

TABLE 4a

Chemical analyses of the composite samples of hay fed during the digestion trials (dry matter basis)

Animal	Dry matter	Crude protein	Ether extract	Crude fiber	Nitrogen free extract	Ash	Gross energy
	%						cal./g.
Control Group							
631	87.6	18.0	3.0	27.7	42.5	8.8	4,323
633	87.6	18.0	3.0	27.7	42.5	8.8	4,323
531-1	87.6	20.9	3.0	22.0	44.1	10.0	4,406
636	86.4	21.3	3.2	21.8	44.6	9.1	4,405
510-1	86.9	20.8	2.5	23.8	43.7	9.2	4,411
296-4	88.2	21.7	2.4	22.8	42.8	10.3	4,414
638	87.7	21.1	3.9	21.7	42.9	10.4	4,422
Mean	87.4	20.3	3.0	23.9	43.3	9.5	4,386
Experimental Group							
632	87.8	19.9	3.6	24.8	41.9	9.8	4,366
438-1	87.8	19.9	3.6	24.8	41.9	9.8	4,366
634	87.8	19.5	2.8	24.3	45.0	8.4	4,364
635	87.6	18.5	2.7	25.2	45.2	8.4	4,406
637	86.8	20.0	3.0	23.8	43.1	10.1	4,400
446-1	86.7	20.5	3.8	23.1	42.9	9.7	4,417
75-3	88.3	20.6	2.9	24.1	42.3	10.1	4,398
Mean	87.5	19.8	3.2	24.3	43.2	9.5	4,388
Over-all Mean	87.5	20.0	3.1	24.1	43.2	9.5	4,387

TABLE 5a

Chemical analyses of the composite samples of hay refused during the digestion trials (dry matter basis)

Animal	Dry matter	Crude protein	Ether extract	Crude fiber	Nitrogen free extract	Ash	Gross energy
	%						cal/g.
Control Group							
631	88.1	23.7	1.8	16.6	48.1	9.8	4,437
633	87.1	21.9	2.3	20.9	45.1	9.8	4,397
531-1	86.5	21.7	2.5	21.7	43.9	10.2	4,425
636	85.9	20.0	1.6	25.1	37.6	15.7	4,393
510-1	86.7	21.7	1.2	21.6	45.7	9.8	4,447
296-4	87.4	25.9	2.0	14.4	45.6	12.1	4,464
638	87.6	21.8	1.9	19.3	46.0	11.0	4,399
Mean	87.0	22.4	1.9	19.9	44.6	11.2	4,423
Experimental Group							
632	87.3	23.8	2.8	17.2	46.1	10.1	4,408
438-1	87.0	23.3	2.0	19.0	45.0	10.7	4,420
634	86.7	24.3	1.5	19.5	43.1	11.6	4,340
635	86.2	24.5	2.1	16.7	45.3	11.4	4,452
637	86.1	21.8	1.2	22.6	43.8	10.6	4,403
446-1	85.7	25.2	1.8	16.7	44.4	11.9	4,472
75-3	87.9	22.9	1.6	19.6	44.4	11.5	4,428
Mean	86.7	23.7	1.9	18.8	44.6	11.1	4,418
Over-all Mean	86.9	23.0	1.9	19.4	44.6	11.2	4,420

TABLE 6a

Average daily body weight gains of the individual calves

Animal	Period I	Period II	Period III	Post-experimental
	lb.			
Control Group				
631	1.11	1.43	1.47	1.12
633	1.00	1.19	1.76	1.03
531-1	0.93	0.86	0.79	0.63
636	0.86	0.90	1.40	0.85
510-1	0.90	1.33	1.69	1.08
296-4	0.57	1.21	2.00	1.09
638	0.90	1.00	2.14	0.85
478-1	0.07	1.47	2.00	1.08
640	0.40	1.36	0.14	0.74
Experimental Group				
632	0.54	0.79	0.61	0.82
438-1	0.90	1.04	0.83	0.78
634	0.64	0.76	0.71	0.68
635	0.43	0.71	0.04	0.27
637	0.57	0.50	0.33	0.33
446-1	1.36	0.64	0.33	0.58
75-3	0.61	1.07	1.43	0.82
639	0.07	0.79	0.71	0.69
502-1	0.11	0.36	0.57	0.82

TABLE 7a

Average daily grain, hay and total dry matter intakes of the individual calves

	Period I			Period II			Period III		
	Grain	Hay	Total	Grain	Hay	Total	Grain	Hay	Total
	lb.								
Control Group									
631	0.50	0.20	0.70	1.55	1.00	2.55	3.00	2.10	5.10
633	0.65	0.03	0.68	1.90	0.30	2.20	4.28	0.75	5.03
531-1	0.43	0.03	0.45	1.50	0.18	1.68	2.68	0.60	3.28
636	0.90	0.15	1.05	1.25	0.60	1.85	3.85	1.20	5.05
510-1	0.43	0.20	0.63	1.28	0.75	2.03	4.25	1.08	5.33
296-4	0.73	0.00	0.73	1.60	0.20	1.80	3.40	1.30	4.70
638	0.48	0.00	0.48	1.40	0.18	1.58	2.65	0.80	3.45
478-1	0.20	0.03	0.23	0.95	1.10	2.05	2.10	2.30	4.40
640	0.00	0.03	0.03	0.25	0.58	0.83	1.00	1.20	2.20
Experimental Group									
632	0.28	0.05	0.33	0.68	0.35	1.03	2.50	0.60	3.10
438-1	0.33	0.03	0.35	0.65	0.40	1.05	2.18	0.90	3.08
634	0.28	0.03	0.30	0.58	0.13	0.70	2.10	0.38	2.48
635	0.38	0.05	0.43	0.58	0.20	0.78	1.20	0.95	2.15
637	0.13	0.03	0.15	0.30	0.10	0.40	1.35	0.28	1.63
446-1	0.25	0.03	0.28	0.30	0.48	0.78	1.17	1.40	2.57
75-3	0.05	0.00	0.05	0.60	0.13	0.73	1.95	0.65	2.60
639	0.05	0.03	0.08	0.23	0.35	0.58	0.90	1.20	2.10
502-1	0.00	0.00	0.00	0.00	0.05	0.05	0.20	0.60	0.80

TABLE 8a

Coefficients of digestibility determined in individual calves during the digestion trials of Period III

	Digestibility coefficient			
	Dry matter	Crude protein	Total nutrients	Energy
	%			
Control group				
631	70.27	73.58	71.40	68.15
633	71.73	74.04	73.27	71.21
531-1	76.32	78.49	78.49	74.76
636	63.68	70.00	64.96	61.18
510-1	64.60	65.79	65.41	62.09
296-4	65.51	66.67	65.16	62.90
638	73.90	76.00	74.30	72.07
Experimental group				
632	61.13	71.79	60.36	58.32
438-1	69.05	76.32	70.21	67.21
634	65.15	73.68	65.44	61.09
635	63.57	64.58	64.75	61.17
637	62.19	51.28	62.63	55.71
446-1	72.32	72.00	73.48	70.46
75-3	69.51	71.05	69.34	67.31

TABLE 9a

Average respiration rates of the individual calves at various air temperatures (^{o}F)[a/]

	Period I			Period II			Period III		
	95°	85°	75°	95°	85°	75°	95°	85°	75°
	respirations/minute								
Control group									
631	44.5	-	-	40.5	-	-	61.0	-	-
633	38.5	-	-	37.0	-	-	66.5	-	-
531-1	26.0	-	-	59.5	-	-	57.5	-	-
636	34.0	-	-	40.0	-	-	51.5	-	-
510-1	29.5	-	-	46.5	-	-	40.0	-	-
296-4	36.8	-	-	47.5	-	-	47.3	-	-
638	34.3	-	-	50.5	-	-	57.0	-	-
478-1	25.5	-	-	33.0	-	-	30.0	-	-
640	40.0	-	-	39.5	-	-	40.0	-	-
Experimental group									
632	81.0	62.0	41.5	94.5	82.5	66.0	106.0	109.0	90.0
438-1	72.0	59.5	34.0	95.3	83.5	51.0	98.3	84.5	75.3
634	99.0	74.0	49.0	100.0	89.0	76.0	91.0	91.5	79.0
635	101.5	76.0	43.5	115.8	97.0	60.5	94.5	83.0	54.0
637	99.5	67.8	37.0	85.3	90.0	63.5	69.5	45.0	35.0
446-1	75.0	69.5	36.0	96.5	82.0	56.0	108.0	85.3	60.0
75-3	98.3	80.5	44.8	106.5	73.5	58.0	118.0	99.0	62.0
639	92.8	78.5	51.5	103.5	91.5	70.0	98.0	85.0	61.0
502-1	121.3	115.3	58.5	110.0	93.0	59.0	116.0	104.0	59.0

a/ Observations on the control-group calves were made at ambient temperature.

TABLE 10a

Average rectal temperatures of the individual calves at various air temperatures (°F)[a/]

	Period I			Period II			Period III		
	95°	85°	75°	95°	85°	75°	95°	85°	75°
	°F								
Control group									
631	103.0	-	-	103.0	-	-	103.6	-	-
633	102.8	-	-	102.9	-	-	103.0	-	-
531-1	102.9	-	-	103.7	-	-	103.4	-	-
636	103.1	-	-	102.7	-	-	103.0	-	-
510-1	102.3	-	-	103.0	-	-	102.9	-	-
296-4	102.8	-	-	103.2	-	-	102.6	-	-
638	102.7	-	-	103.1	-	-	103.0	-	-
478-1	102.4	-	-	103.0	-	-	103.6	-	-
640	102.9	-	-	102.5	-	-	102.7	-	-
Experimental group									
632	104.8	104.0	103.8	104.8	104.3	104.0	105.3	105.6	104.6
438-1	104.0	103.5	103.6	104.9	104.9	104.4	105.2	105.2	104.7
634	104.4	103.6	103.8	104.7	104.5	104.3	105.2	104.9	104.3
635	104.7	104.3	103.9	105.4	105.4	104.3	105.8	105.9	104.2
637	105.4	104.3	104.0	106.5	106.4	105.0	105.6	105.1	104.1
446-1	104.8	104.5	104.0	104.9	104.8	103.8	105.6	105.1	104.0
75-3	102.8	103.0	102.8	103.0	103.4	102.5	103.5	103.9	103.2
639	104.8	104.7	103.6	104.6	104.8	103.0	104.7	104.8	103.3
502-1	106.0	106.2	104.0	105.6	105.3	103.1	105.8	105.8	103.6

a/ Observations on the control-group calves were made at ambient air temperature.

TABLE 11a

Average hematocrit values and hemoglobin levels of the individual calves

	Period I		Period II		Period III	
	hemato-crit	hemo-globin	hemato-crit	hemo-globin	hemato-crit	hemo-globin
	%	gm./100 ml.	%	gm./100 ml.	%	gm./100 ml.
Control group						
631	47.8	10.26	45.3	9.77	41.0	9.03
633	47.8	10.70	41.0	8.52	38.3	8.67
531-1	49.0	10.66	41.5	8.38	32.7	7.50
636	53.0	11.44	43.2	9.45	39.0	9.07
510-1	34.8	7.56	31.7	7.02	37.0	8.53
296-4	47.6	10.56	41.8	9.50	38.5	8.90
638	55.6	11.92	44.0	9.88	37.0	8.40
478-1	48.4	10.56	34.8	8.00	36.0	8.00
640	51.2	11.48	37.0	8.25	-	-
Experimental group						
632	39.2	8.90	35.0	7.43	35.0	7.63
438-1	39.4	8.54	32.5	7.02	35.0	7.43
634	37.8	8.42	34.8	7.37	36.7	8.07
635	53.2	12.14	38.3	8.57	28.3	6.57
637	42.0	8.88	32.2	6.98	28.3	6.40
446-1	27.4	6.46	22.0	5.25	25.3	5.97
75-3	27.2	6.78	25.7	6.38	32.0	7.35
639	55.0	12.50	42.2	9.33	-	-
502-1	55.0	7.96	42.2	5.35	-	-

TABLE 12a

Average blood plasma carotenoid and vitamin A levels of the individual calves

	Period I		Period II		Period III	
	carot-enoid	vitamin A	carot-enoid	vitamin A	carot-enoid	vitamin A
	mcg./100 ml.					
Control group						
631	48.0	17.36	131.2	26.33	259.7	21.80
633	40.4	18.32	91.3	29.67	133.3	27.47
531-1	17.8	18.88	34.7	24.20	83.0	16.87
636	43.8	24.26	113.7	26.20	154.7	29.50
510-1	37.8	21.26	76.3	25.83	136.7	27.97
296-4	31.8	19.00	66.2	25.25	295.0	28.30
638	31.8	14.08	43.3	18.43	136.0	22.90
478-1	23.4	19.90	126.2	29.28	297.0	36.40
640	34.8	15.76	72.2	22.55	-	-
Experimental group						
632	25.6	21.76	57.0	22.92	77.7	17.13
438-1	33.8	18.58	124.8	26.07	192.0	18.80
634	34.8	21.66	32.7	19.23	48.3	14.80
635	25.4	24.14	30.0	22.62	93.7	14.70
637	29.0	24.74	34.3	32.27	46.3	16.53
446-1	28.6	18.32	61.2	25.12	190.3	19.17
75-3	19.0	11.50	29.2	22.85	202.0	27.30
639	18.4	17.46	41.5	18.93	-	-
502-1	14.6	11.38	12.3	14.65	-	-

TABLE 13a

Average levels of serum total protein and albumin and albumin/globulin ratios of the individual calves

	Period I			Period II			Period III		
	Total protein	Albumin	A/G ratio	Total protein	Albumin	A/G ratio	Total protein	Albumin	A/G ratio
	gm./100 ml.								
Control group									
631	6.87	1.99	0.41	6.18	2.30	0.59	6.29	2.27	0.57
633	7.02	1.98	0.40	6.23	2.16	0.53	6.50	2.41	0.59
531-1	7.08	1.77	0.34	5.98	1.87	0.46	6.39	2.17	0.51
636	6.47	2.15	0.50	6.41	2.14	0.50	6.57	2.37	0.58
510-1	6.09	1.93	0.47	5.94	2.23	0.60	6.58	2.63	0.66
296-4	5.23	1.97	0.61	5.87	2.21	0.62	6.28	2.58	0.70
638	5.65	1.95	0.53	6.23	2.05	0.50	6.35	2.29	0.56
478-1	6.46	2.30	0.57	6.02	2.27	0.62	6.03	2.40	0.66
640	6.11	1.96	0.47	6.17	2.22	0.57	-	-	-
Experimental group									
632	6.14	2.09	0.52	5.79	2.22	0.62	6.37	2.17	0.51
438-1	5.28	2.06	0.65	5.41	2.34	0.76	6.14	2.52	0.71
634	5.93	1.98	0.51	5.59	2.07	0.60	6.05	2.06	0.52
635	6.51	1.85	0.41	5.80	2.20	0.61	6.21	2.28	0.59
637	7.11	1.84	0.36	6.32	2.13	0.51	6.57	2.20	0.51
446-1	4.63	1.78	0.63	5.51	2.21	0.68	6.09	2.50	0.70
75-3	4.48	1.57	0.54	5.07	1.72	0.52	5.60	2.22	0.66
639	5.13	1.65	0.48	5.66	2.11	0.60	-	-	-
602-1	4.64	1.84	0.67	5.04	2.01	0.69	-	-	-

TABLE 14a

Average levels of serum alpha-, beta-, and gamma-globulins of the individual calves

	Alpha	Beta	Gamma	Alpha	Beta	Gamma	Alpha	Beta	Gamma
	gm./100 ml.								
Control group									
631	1.03	1.73	2.11	0.99	1.64	1.25	1.10	1.57	1.34
633	1.25	1.72	2.08	1.09	1.53	1.45	1.17	1.43	1.50
531-1	1.18	1.68	2.45	1.10	1.50	1.51	1.16	1.41	1.65
636	1.35	1.67	1.31	1.20	1.53	1.54	1.18	1.59	1.42
510-1	1.58	1.48	1.10	1.10	1.44	1.17	1.17	1.38	1.40
296-4	1.60	1.15	0.51	1.29	1.36	1.01	1.37	1.22	1.10
638	1.37	1.34	0.99	1.24	1.50	1.43	1.20	1.09	1.77
478-1	1.39	1.42	1.34	1.16	1.33	1.26	1.12	1.36	1.16
640	1.25	1.54	1.36	1.04	1.33	1.58	-	-	-
Experimental group									
632	1.18	1.64	1.23	0.98	1.48	1.10	1.07	1.72	1.42
438-1	1.38	1.18	0.65	0.95	1.20	0.92	1.02	1.39	1.22
634	1.24	1.67	1.04	1.16	1.35	1.00	1.02	1.42	1.55
635	1.34	1.93	1.40	1.08	1.34	1.17	1.15	1.40	1.38
637	1.05	2.21	2.01	0.98	1.65	1.56	1.11	1.42	1.84
446-1	1.45	1.01	0.40	1.07	1.20	1.03	0.85	1.19	1.55
75-3	1.45	1.04	0.41	1.07	1.30	0.98	0.90	1.32	1.16
639	1.39	1.28	0.81	1.15	1.26	1.15	-	-	-
502-1	1.36	0.97	0.45	1.06	1.05	0.92	-	-	-

TABLE 15a

Analysis of variance of the body weight gain data

Variance source	Period							
	I		II		III		Post-experimental	
	df	MS	df	MS	df	MS	df	MS
Between groups	1	31.000	1	181.00**	1	580.00**	1	5868.4**
Between sexes	1	0	1	3.00	1	25.00	1	940.9
Group X sex interaction	1	48.000	1	0	1	13.00	1	298.5
Among animals within group sex	14	29.429	14	11.286	14	33.50**	14	538.3
Residual	54	68.019	54	14.963	36	11.83		

**F test significant at $P < 0.01$ level.

TABLE 16a

Analysis of variance of the whole milk and skim milk intake data

Variance source	Whole milk		Skim milk			
	Period I		Period I		Period II	
	df	MS	df	MS	df	MS
Between groups	1	0.0200	1	1.1900	1	0.0600
Between sexes	1	0.7800	1	1.1000	1	0.1200
Group X sex interaction	1	1.3000	1	1.6000	1	0.8000
Among animals within group-sex	14	1.4150	14	4.3864	14	0.4900
Residual	54	7.0380	54	13.7152	54	0.8315

TABLE 17a

Analysis of variance of the grain dry matter intake data

Variance source	Period I		Period II		Period III	
	df	MS	df	MS	df	MS
Between groups	1	1.4700*	1	13.4400**	1	37.5000**
Between sexes	1	0.0700	1	0	1	0.0700
Group X sex interaction	1	0	1	0.0700	1	0.2700
Among animals within group-sex	14	0.2029*	14	0.6314**	14	1.9393**
Residual	54	0.1046	54	0.0452	36	0.4981

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 18a

Analysis of variance of the hay dry matter intake data

Variance source	Period I		Period II		Period III	
	df	MS	df	MS	df	MS
Between groups	1	0.0300	1	1.6200*	1	2.7500
Between sexes	1	0	1	0.0200	1	0.2500
Group X sex interaction	1	0	1	0	1	1.2600
Among animals within group-sex	14	0.0114	14	0.3414**	14	0.6357**
Residual	54	0.0087	54	0.0315	36	0.0850

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 19a

Analysis of variance of the total (grain plus hay) dry matter intake data

Variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
Between groups	1	2.0000*	1	24.3800**	1	62.7200**
Between sexes	1	0.1100	1	0.0100	1	0
Group X sex interaction	1	0	1	0.0800	1	0.5000
Among animals within group-sex	14	0.2486	14	0.7364**	14	1.9786**
Residual	54	0.1472	54	0.1181	36	0.6256

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 20a

Analysis of variance of the digestibility data

Variance source	df	Mean Square: Dry matter	Crude protein	Total nutrients	Energy
Between groups	1	38.082	40.698	51.226	69.042
Between sexes	1	32.931	18.954	35.319	50.622
Group X sex interaction	1	60.025	101.448	69.596	100.410*
Among animals within group-sex	10	15.856	44.455	19.427	20.110

*F test significant at $P < 0.05$ level.

TABLE 21a

Analysis of variance of the respiration rate data

Variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
	Control group vs. experimental group at 95°F					
Between groups	1	62,717**	1	58,538**	1	25,742**
Between sexes	1	634	1	241	1	3
Group X sex interaction	1	143	1	38	1	2,464*
Among animals within group-sex	14	577	14	322	14	374
Residual	54	334	54	274	36	360
	Control group vs. experimental group at 85°F					
Between groups	1	31,084**	1	33,453**	1	13,792**
Between sexes	1	3	1	15	1	149
Group X sex interaction	1	1,495	1	655	1	1,006
Among animals within group-sex	14	601**	14	217	14	790**
Residual	54	246	54	222	36	180
	Control group vs. experimental group at 75°F					
Between groups	1	1,673**	1	6,122**	1	1,956
Between sexes	1	444	1	163	1	384
Group X sex interaction	1	258	1	1,186*	1	460
Among animals within group-sex	14	190	14	184	14	690**
Residual	54	131	54	169	36	124

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 22a

Analysis of variance of the rectal temperature data

Variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
	Control group vs. experimental group at 95°F					
Between groups	1	62.900**	1	66.510**	1	66.000**
Between sexes	1	2.490	1	0.290	1	1.780
Group X sex interaction	1	0.080	1	4.210	1	0
Among animals within group-sex	14	1.784**	14	1.906**	14	0.684*
Residual	54	0.320	54	0.306	36	0.326
	Control group vs. experimental group at 85°F					
Between groups	1	40.350**	1	62.910**	1	59.960**
Between sexes	1	0.190	1	0.100	1	1.370
Group X sex interaction	1	0.780	1	3.340	1	0
Among animals within group-sex	14	2.056**	14	1.620**	14	0.554
Residual	54	0.297	54	0.249	36	0.310
	Control group vs. experimental group at 75°F					
Between groups	1	16.440**	1	12.750**	1	15.460**
Between sexes	1	1.320	1	0.420	1	0.650
Group X sex interaction	1	0.020	1	4.730	1	0
Among animals with group-sex	14	0.442	14	1.427**	14	0.500
Residual	54	0.264	54	0.375	36	0.372

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 23a

Analysis of variance of the hematocrit data

Variance source	Period I		Period II		Period III	
	df	MS	df	MS	df	MS
Between groups	1	966.0	1	1026.0*	1	360.0**
Between sexes	1	1139.0	1	743.0	1	37.0
Group X sex interaction	1	24.0	1	11.0	1	28.0
Among animals within group-sex	14	343.4**	14	176.9**	14	27.3**
Residual	72	21.7	90	13.4	21	8.5

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 24a

Analysis of variance of the hemoglobin data

Variance source	Period I		Period II		Period III	
	df	MS	df	MS	df	MS
Between groups	1	58.880*	1	75.830**	1	22.300**
Between sexes	1	91.480**	1	55.480**	1	1.260
Group X sex interaction	1	11.020	1	6.520	1	1.230
Among animals within group-sex	14	9.714**	14	4.872**	14	0.938*
Residual	72	0.868	90	0.391	21	0.387

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 25a

Analysis of variance of plasma carotenoid data

Variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
Between groups	1	1,795.0*	1	36,741*	1	32,271
Between sexes	1	1,200.0	1	71	1	40,566*
Group X sex interaction	1	493.0	1	6,944	1	37,488*
Among animals within group-sex	14	278.6**	14	7,258**	14	7,697**
Residual	72	103.3	90	1,470	21	1,174

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 26a

Covariance analysis of plasma carotenoid level adjusted for carotenoid intake

Adjusted variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
Between groups	1	853.45	1	300.8	1	397
Between sexes	1	384.09	1	0.9	1	12,877*
Group X sex interaction	1	489.98	1	6,698.2	1	10,827
Among animals within group-sex	14	253.92*	14	3,386.2**	14	4,876.**
Error term 1	13	209.52	13	3,404.6	13	2,646
Error term 2	71	129.62	89	770.0	20	1,151

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 27a

Analysis of variance of plasma vitamin A data

Variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
Between groups	1	0.14	1	177.87	1	580.07**
Between sexes	1	150.39	1	1.55	1	80.58
Group X sex interaction	1	431.29*	1	42.59	1	54.72
Among animals within group-sex	14	52.04	14	122.32**	14	42.79
Residual	72	30.86	90	20.08	21	22.57

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 28a

Covariance analysis of plasma vitamin A level adjusted for carotenoid intake

Adjusted variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
Between groups	1	17.04	1	14.92	1	224.26*
Between sexes	1	38.69	1	0.60	1	42.62
Group X sex interaction	1	439.60**	1	43.57	1	23.22
Among animals within group-sex	14	63.47**	14	111.90**	14	41.77
Error term 1	13	40.81	13	120.51	13	42.27
Error term 2	71	25.09	89	19.34	20	22.07

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 29a

Analysis of variance of serum total protein data

Variance source	Period I		Period II		Period III	
	df	MS	df	MS	df	MS
Between groups	1	14.145*	1	7.7816**	1	0.5844*
Between sexes	1	14.539*	1	4.9987**	1	0.2596
Group X sex interaction	1	8.023	1	0.5316	1	0.2217
Among animals within group-sex	14	1.992**	14	0.2377**	14	0.0889
Residual	72	0.170	90	0.0522	21	0.0946

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 30a

Covariance analysis of serum total protein level adjusted for protein intake

Adjusted variance source	Period I		Period II		Period III	
	df	MS	df	MS	df	MS
Between groups	1	9.344	1	0.8609	1	0.0888
Between sexes	1	13.671*	1	4.6642**	1	0.2452
Group X sex interaction	1	7.666	1	0.4811	1	0.2128
Among animals within group-sex	14	20.172**	14	0.2292**	14	0.1002
Error term 1	13	2.144	13	0.2437	13	0.0957
Error term 2	71	0.157	89	0.0654	20	0.0834

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 31a

Analysis of variance of serum albumin data

Variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
Between groups	1	0.4914	1	0.0607	1	0.1169
Between sexes	1	0.0382	1	0.0733	1	0.3293*
Group X sex interaction	1	0.0175	1	0.0163	1	0.0379
Among animals within group-sex	14	0.1448**	14	0.1558**	14	0.0425
Residual	72	0.0551	90	0.0518	21	0.0453

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 32a

Covariance analysis of serum albumin level adjusted for serum total protein

Adjusted variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
Between groups	1	0.1582	1	0.0705	1	0.0032
Between sexes	1	0.0002	1	0.0399	1	0.4728**
Group X interaction	1	0.0005	1	0.0033	1	0.1255
Among animals within group-sex	14	0.1389**	14	0.1396**	14	0.0340
Error term 1	13	0.1490	13	0.1502	13	0.0336
Error term 2	71	0.0557	89	0.0480	20	0.0458

**F test significant at $P < 0.01$ level.

TABLE 33a

Analysis of variance of serum alpha-globulin data

Variance source	Period I		Period II		Period III	
	df	MS	df	MS	df	MS
Between groups	1	0.0072	1	0.1594	1	0.2415**
Between sexes	1	0.7084*	1	0.0019	1	0.0200
Group X sex interaction	1	0.0018	1	0.0501	1	0.1226**
Among animals within group-sex	14	0.0948*	14	0.0466*	14	0.0113
Residual	72	0.0475	90	0.0230	21	0.0311

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 34a

Covariance analysis of serum alpha-globulin level adjusted for serum total protein

Adjusted variance source	Period I		Period II		Period III	
	df	MS	df	MS	df	MS
Between groups	1	0.3325*	1	0.1841	1	0.1908**
Between sexes	1	0.0290	1	0.0279	1	0.0712**
Group X sex interaction	1	0.2016	1	0.0907	1	0.1476**
Among animals within group-sex	14	0.1832**	14	0.0526**	14	0.0135
Error term 1	13	0.0433	13	0.0453	13	0.0069
Error term 2	71	0.0306	89	0.0222	20	0.0241

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 35a

Analysis of variance of serum beta-globulin data

Variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
Between groups	1	0.1699	1	0.5910*	1	0.0008
Between sexes	1	4.1222**	1	0.7016*	1	0.2507*
Group X sex interaction	1	1.5570*	1	0.1134	1	0.0108
Among animals within group-sex	14	0.2688**	14	0.0821**	14	0.0387
Residual	72	0.0422	90	0.0297	21	0.0241

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 36a

Covariance analysis of serum beta-globulin level adjusted for serum total protein

Adjusted variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
Between groups	1	0.5146**	1	0.0057	1	0.0017
Between sexes	1	0.3403**	1	0.0048	1	0.2549*
Group X sex interaction	1	0.0583	1	0.0086	1	0
Among animals within group-sex	14	0.0363	14	0.0608*	14	0.0377
Error term 1	13	0.0360	13	0.0613	13	0.0406
Error term 2	71	0.0297	89	0.0287	20	0.0239

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 37a

Analysis of variance of serum gamma-globulin data

Variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
Between groups	1	6.5448*	1	1.8696**	1	0.0117
Between sexes	1	5.9892	1	1.3620*	1	0.1959
Group X sex interaction	1	2.0220	1	0.0019	1	0.0503
Among animals within group-sex	14	1.3782**	14	0.1677**	14	0.0854
Residual	72	0.0853	90	0.0494	21	0.0447

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 38a

Covariance analysis of serum gamma-globulin level adjusted for serum total protein

Adjusted variance source	Period I df	Period I MS	Period II df	Period II MS	Period III df	Period III MS
Between groups	1	0.0657	1	0.0083	1	0.1442
Between sexes	1	0.1422	1	0.0016	1	0.0356
Group X sex interaction	1	0.4273	1	0.1103	1	0
Among animals within group-sex	14	0.3064**	14	0.0984**	14	0.0666*
Error term 1	13	0.2325	13	0.1032	13	0.0717
Error term 2	71	0.0618	89	0.0409	20	0.0266

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

TABLE 39a

Analysis of variance of serum albumin/globulin ratio data

Variance source	Period I		Period II		Period III	
	df	MS	df	MS	df	MS
Between groups	1	0.0613	1	0.1226	1	0
Between sexes	1	0.2244*	1	0.0793	1	0.1006**
Group X sex interaction	1	0.1033	1	0.0106	1	0.0327*
Among animals within group-sex	14	0.0298**	14	0.0275**	14	0.0050
Residual	72	0.0089	90	0.0096	21	0.0086

*F test significant at $P < 0.05$ level.

**F test significant at $P < 0.01$ level.

AUTOBIOGRAPHY

The author was born at Jamaica, New York on September 16, 1937. He lived his early years at Queens Village, New York and in 1944 moved to Tuckahoe, New York, where he attended primary and secondary schools. He matriculated in Rutgers University, New Brunswick, New Jersey, in September, 1954 and majored in dairy husbandry. In June, 1958 he received his Bachelor of Science Degree. He entered the Graduate School of Rutgers University in July of the same year and worked toward his Master of Science Degree at the Dairy Research Farm, Sussex, New Jersey, under the guidance of Dr. Robert E. Mather. His thesis topic was the heretability of roughage consumption in Holstein cattle. After receiving his Master of Science Degree in June, 1960, the author came to Louisiana State University in September of the same year. At the latter institution he worked toward the Doctor of Philosophy Degree under the guidance of Dr. Louis L. Rusoff. He completed the requirements for the degree in January, 1963.

EXAMINATION AND THESIS REPORT

Candidate: Paul Folling Randel

Major Field: Dairy Nutrition

Title of Thesis: The Effect of Simulated Louisiana Summer Conditions on Newborn Dairy Calves. I. Growth, Feed Intake, Digestibility, Plasma Protein and Certain Other Blood Constituents.

Approved:

L. L. Ruisoff
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